XIII.—*The Old Red Sandstone of the Orkneys.* By John S. Flett, M.B., B.Sc. (With a Map.)

(Read 17th January 1898.)

Literature.

The first geologist to examine critically the Old Red Sandstone of the Orkneys seems to have been Professor Jameson, who in 1800 spent six weeks in a mineralogical tour through the county, and so barren did he find the islands, from his point of view, that he counted his journey one of the most uninteresting he had ever made. As yet, the rich store of organic remains which the dark grey flagstones contained had not been brought to light, but the stimulus given to this branch of investigation by the work of Hugh Miller and Agassiz awakened interest in the subject, and we find that a number of collections was formed, especially from the quarries in the neighbourhood of the town of Stromness. Hence when, at a later period (1848), Hugh Miller paid a visit to this district, as narrated in his *Footprints of the Creator, or the Asterolepis of Stromness*, many of the fossils of these rocks were already well known to local collectors, among whom he mentions particularly the late Mr W. Watt of Skaill and Dr Garson of Stromness. Professor Traill of Edinburgh University had for many years been forming a collection, and specimens had been forwarded by him to Agassiz, who makes mention of the fact. Hugh Miller, in the work above cited, and in his *Cruise of the Betsy* (1858), gives a description of his visit to Kirkwall, Stromness, and various parts of the West Mainland, which contains many interesting facts relating to the occurrence and distribution of the fossils in these districts. Further reference to his work will be found in a subsequent part of this paper. The general similarity of the rocks around Stromness to the sandstones of Cromarty and the flagstones of Caithness, as regards the fossils they contained, may be regarded as well established at this date, and the subsequent descriptions of Orcadian specimens contained in Professor M'Coy's *Synopsis of Classification of British Palæozoic Rocks* (1858) served in some measure to confirm this opinion. So far, there had been no attempt to ascertain the structure of the county, but in 1858 Sir R. Murchison* made a brief survey of the islands. He ascertained that there were at least two main types of sedimentary deposits in the Old Red Sandstone of Orkney,—a lower series of flagstones and, overlying them, conformably, as he believed, a series of yellow sandstones, well seen in the island of Hoy. The lower series at Stromness rested, by means of a basement conglomerate, upon an axis of crystalline rock. A great advance was made in 1878 by the appearance of the first part of Sir Archibald Geikie's mono-

* Sir R. Murchison, *Quart. Jour. Geol. Soc.*, vol. xv.

graph on the Old Red Sandstone of Western Europe.* As the result of two visits to Orkney, in which he was accompanied by Mr B. N. Peach, he pointed out that the yellow sandstones of Hoy did not pass down conformably into the flagstones which form the basis of that island, but were separated from them by a marked unconformity. At the base of the upper sandstones lay a series of contemporaneous lavas and ash beds, which were in all probability erupted from certain 'necks' in the low-lying district at the foot of the Hoy Hills. These rocks he regarded as belonging to the upper Old Red Sandstone. The lower Old Red Sandstone consisted principally of a great thickness of flagstones, with which were interstratified beds of yellow and red sandstone, and occasionally of conglomerate. The fossils belonged exclusively to this lower series; and a table is given, compiled by Mr C. W. Peach, showing the distribution of fossil fishes in the lower Old Red Sandstone of Lake Orcadie, including those of Orkney so far as known at that time. As Sir Archibald Geikie anticipated, subsequent revision has necessitated "considerable pruning of the fossil lists." The conglomerates around the granite axis of Stromness formed merely a local base, "due to the uprise of an old ridge of rock from the surface of the sheet of water in which these strata were accumulated," and were presumably not on the same horizon as the thick conglomerates on which, in Caithness, the lowest flagstones rest. The sandstones interbedded with the flagstones in South Ronaldshay were regarded as in all probability the northward continuation of the similar rocks at Gill's Bay, Huna, and John o' Groats, on the south side of the Pentland Firth. From a geological point of view, the brief notice of the Old Red Sandstone of the Orkneys contained in this paper forms by far the most important contribution to the knowledge of the subject published up to that time.

In two papers on the Geognosy of Orkney,† published in December 1879, Professor Foster Heddle showed the existence of a well-marked syncline beginning in the North Isles in the island of Eday, and continuing thence through Shapinshay and Inganess Bay to Scapa and the north-west corner of South Ronaldshay. The beds which occupy the centre of this trough are coarse arenaceous freestones, which rest perfectly conformably on the ordinary blue flags of the islands, and at Heclabir, in Sanday, contain thin beds of conglomerate. These sandstones cannot, in consequence, be the same as the yellow sandstones of Hoy, which unconformably overlie the flags. In these papers many interesting details are given of the minerals occurring in the islands, and of the structural peculiarities of the flagstones, especially as seen in the magnificent coast sections.

In 1880 Messrs Peach and Horne made a much more detailed examination of the islands than had previously been attempted, and the result was an important paper on the Old Red Sandstone of Orkney.‡ They showed that in all probability the upper Old Red Sandstone of the district was confined to the island of Hoy, while the rest of the

* Sir Arch. Geikie, "The Old Red Sandstone of Western Europe," pt. i., *Trans. Roy. Soc. Edin.*, vol. xxviii. pp. 409 and 410.

† *Mineralogical Magazine*, "The Geognosy and Mineralogy of Scotland," part v.—Orkney, M. Foster Heddle, M.D., 1880, p. 102.

‡ *Proc. Roy. Phys. Soc. Edin.* 1880

county consisted of the flagstones and sandstones of the lower series. The distribution of these two members was described, and sections given to show their relation to one another. In their paper on the Glaciation of the Orkney Islands* a map was published, which reappears in the chapter contributed by them to Tudor's *The Orkneys and Shetland*,† and leaves little to be desired so far as regards a knowledge of the distribution of the different lithological types which constitute the Old Red Sandstone of the Orkneys. The structure of the county, they regarded, with Professor HEDDLE, as, in the main, a syncline which runs from Eday to South Ronaldshay, broken in the Mainland by two great faults which cross it and follow the shores of Scapa Bay. In the centre of this syncline lie the sandstones which form the uppermost member of the lower series, while the flagstones form the rest of the district, with the exception of the area occupied by the upper Old Red Sandstone in the island of Hoy. They showed also that in Shapinshay, among the yellow sandstones of the lower Old Red, occurred a belt of contemporaneous volcanic rocks, consisting of a single outflow of a diabasic lava.‡

I.—The Palæontological Subdivisions of the Orcadian Old Red Sandstone.

The Eday Sandstones.—So far, those geologists who had endeavoured to make out the structure and succession of the Orcadian Old Red Sandstone had relied mostly on the different types of sedimentary rocks to establish their conclusions, without reference to the fossils the rocks contained. But in 1896, in a paper read to the Royal Physical Society of Edinburgh,§ the present writer showed that among the yellow sandstones of the lower Old Red Sandstone of Deerness, Orkney, occurred three fossils not previously recorded from Orkney, and known only to occur in the John o' Groats sandstones of Caithness, viz., *Dipterus macropterus* (Traq.), *Tristichopterus alatus* (Egert.), and *Microbrachius Dicki* (Traquair). In this way the opinion, already expressed by previous authors,‖ that the sandstones which conformably overlie the flagstones in Orkney were the northern representatives of the similar beds at John o' Groats, Caithness, was confirmed by palæontological evidence. During the following summer investigation was made whether the sandstones in other districts of Orkney, to which had been assigned the same position, contained the same suite of fossils, with the result that in several of the localities examined (in Shapinshay, Inganess Bay, and Eday) one or other of them was proved to occur, and it was established that they constituted the type fossils of a palæontological zone of the Orcadian Old Red Sandstone, which was at the same time distinguished by the lithological characters of its rocks. This may, in consequence, be designated the zone of *Tristichopterus alatus* (Egert.), or, from the locality in Orkney in which they have been principally studied, *the Eday sandstones.*

* *Quart. Jour. Geol. Soc. Lond.*, vol. 36.

† London, 1883.

‡ The occurrence of this basalt was noted by JAMESON, *Mineralogy of the Scottish Isles*, ii. 235.

§ *Proc. Roy. Phys. Soc. Edin.*, vol. xiii.

‖ PEACH and HORNE, *op. cit.* Sir A. GEIKIE *Old Red Sandstone*, p. 409.

As will be shown in a subsequent part of this paper, they fall naturally into two subdivisions, a yellow series beneath and a red series above; and it is the thin layers of flag intercalated in the yellow sandstones which have furnished the fossils described. A no less striking characteristic of these beds is the occurrence in them of that zone of volcanic rocks of which the first mention was made by Professor JAMESON.*

The Rousay Beds.—The inquiry was next advanced into the beds which underlie this zone, and were known to consist of a series of flagstones, presumably of great thickness, and of wide distribution throughout the county. All efforts to break up this series into recognisable subdivisions by means of belts of rock, with sufficiently well-developed peculiarities to ensure their recognition in different districts, had hitherto failed;† and, from an extensive knowledge of these rocks, the present writer felt that success was hardly to be hoped for in such an attempt. But should the distribution of their fossils show that certain forms occurred only on particular horizons, this great series could be broken up into zones, which could be identified wherever they occurred, if only they contained a sufficient number of organic remains in a satisfactory state of preservation. The base of the Eday sandstones was chosen as forming a well defined horizon, from which it would be possible to work downwards into the flagstone series in search of type fossils. These underlying beds were then followed from Eday, Westray, and Sanday in the north to South Ronaldshay in the south; the geological structure being carefully mapped, and a record of the fossils observed in each district compiled at the same time. The flagstones of these districts proved to be barren and unfossiliferous compared with the well known localities, chiefly in the West Mainland of Orkney, from which for many years fossils had been obtained in great numbers. Yet in every district decipherable fragments were to be found; and in some localities the fossils were quite as satisfactory as in the better known beds of the West Mainland. By far the most common were the sculptured bones and scales of *Glyptolepis paucidens* (Agassiz), which occurred in every district examined, often in great profusion, and with them *Dipterus valencienesii* (Sedgwick and Murchison), in every locality, and almost equally abundant. In fact, both these fossils occur right up to the base of the Eday sandstones, though as yet in Orkney not known with certainty to pass up into these overlying rocks. In Deerness, Holm, and Eday the beds immediately below the sandstones are crowded with *Dipterus valencienesii* (Sedgwick and Murchison), often in fine preservation, and covering the surface of whole slabs of rock. After these in frequency comes *Homosteus Milleri* (Traquair), of which the large and usually broken plates are often to be seen. Other fossils were relatively few. In Crook Bay, Shapinshay, I found a Cheiracanthus, which when submitted to Dr TRAQUAIR was determined to be *Cheiracanthus Murchisoni* (Agassiz). At Dingieshowie, Deerness, at Kirkwall, and elsewhere, *Osteolepis macrolepedotus* (Ag.) is found. *Diplopterus Agassizi* (Traill) occurs in the East Mainland, *Estheria membranacea* at Kirkwall, Rendall, and Westray. *Coccosteus decipiens* (Ag.) at Kirkwall, Dingieshowie, and even in the sandstones at Deerness, as I learned from Mr

* *Op. cit.*

† ARCHIBALD GEIKIE, *op. cit.*, p. 410.

Magnus Spence of Deerness, who forwarded a specimen he found in Newark Bay to Dr Traquair. To these we must add a new and undescribed species of Asterolepis, of which scattered plates were found by Mr Spence of Deerness and myself in Deerness, Holm, and South Ronaldshay. These have been presented by us to the Edinburgh Museum of Science and Art, and Dr Traquair has kindly consented to draw up and publish a description of them. This interesting fossil is, so far as we know at present, confined to a narrow belt of the flagstones immediately underlying the Eday sandstones, where it occurs with *Dipterus valencienesii* (Sedgwick and Murchison), and *Glyptolepis paucidens* (Ag.); and should further investigations confirm this restricted distribution, it may eventually be taken to mark the existence of a palæontological sub-zone immediately beneath that of *Tristichopterus alatus* (Egert.). That already it should be known from three localities widely separated, and in each case from precisely the same horizon, shows that it can hardly be called a rare fossil in Orkney, and in the future further specimens may be confidently expected to turn up should these beds be submitted to careful and extended investigation. With this exception, this list of fossils contains none which is not of very general distribution throughout the whole thickness of the Orcadian flags.

But when, in the progress of the mapping, a layer of rocks occupying a somewhat lower position was reached, fossils were obtained which were new to Orkney, or among the very rarest of those recorded from it. In the island of Rousay I found along the west side a belt of rocks containing *Coccosteus minor* (Miller), the best specimens being obtained in a quarry of thin slaty flagstones near Sacquoy Head. With it occurred the large enamelled scales of a ganoid fish, of which the fragmentary remains were not sufficient for satisfactory determination. Application was made to the proprietor of the island, General Burroughs, for liberty to quarry, and permission was at once granted. Better material was thus procured, and all doubt removed by the discovery of well preserved remains of *Thursius pholidotus* (Traquair), an addition to the list of the fossil fishes of Orkney. Both occurred on the same bed of rock, and are here recorded from Orkney, one for the first time, the other after a lapse of almost forty years, during which the knowledge of its occurrence seems practically to have disappeared. Curiously enough, when, at a subsequent time, at my request, Dr Traquair examined for me certain plates of *Coccosteus minor* (Miller) preserved in the British Museum,* which, I presumed, had come from another locality mentioned by Hugh Miller, he informed me that these specimens, which belonged to the Egerton Collection, were derived from the same locality, but when or by whom they were collected is not known. A very careful search, a year or more previously, among all the local collections of fossil fishes, had failed to bring under my notice any remains of this fish, and none seem to have passed through Dr Traquair's hands, as he comments on its apparent absence from the north side of the Pentland Firth.†

* A. Smith Woodward, B.M. Cat.—Fossil Fishes, pt. ii. p. 291.

† "Achanarras Revisited," *Proc. Roy. Phys. Soc. Edin.*, xii. 285.

Hugh Miller, in his *Cruise of the Betsy* (1858), p. 358, narrates how, during his stay in Kirkwall, he paid a visit to a quarry a few hundred yards to the east of the town, where he observed numerous specimens of a species of Coccosteus, which he regarded as the same as those he had received from the neighbourhood of Thurso (collected by Robert Dick), and as certainly distinct from, and not merely young forms of, the common *Coccosteus decipiens* (Agassiz). For these he extemporises the name of *Coccosteus minor*. As no specimens of this fossil from Orkney were contained in his collection, and no further material had been obtained from this locality for many years, the accuracy of this observation remained open to some doubt, in spite of his careful identification. Unfortunately, these quarries are now practically worked out and deserted, but I can remember, years ago, seeing in the stones of some old houses in Kirkwall, which had evidently come from this quarry, great numbers of very minute specimens of a Coccosteus. With the rediscovery of this species, however, these doubts in great measure are removed; and as I shall subsequently show, the horizon of these rocks in the vicinity of Kirkwall is identical with that of the beds which in Rousay contain the same fossils. Hence, there is every presumption that this is another locality in Orkney for this species.

In the extreme south end of South Ronaldshay, I found at Banks Geo further examples of the same species, and as here they occur at no great distance from the Eday sandstone series of this island, it would seem that the horizon is a somewhat higher one than that in which it occurs in Rousay and in Kirkwall; but as the island is traversed by a number of faults, no very great reliance can be placed on any estimates of the thickness of the intervening rocks.

Here, then, we have from three localities—one in the north, one in the centre, and one in the south of the county, the extreme stations being over thirty miles apart—the occurrence of a distinct and characteristic fossil in the flagstones. With it occurs another *Thursius pholidotus* (Traquair), which is nowhere known except accompanying it. From the many quarries in the West Mainland, from which for seventy years innumerable specimens have been obtained, not one case is known in which these have been found, and it may safely be presumed that there they do not occur. Their absence, at any rate, cannot be accounted for by imperfect preservation or insufficient search. They may be assumed, in consequence, to constitute the type fossils of a zone of the Orcadian Old Red Sandstone beneath that already defined for the Eday sandstones, and the beds in which they occur I shall designate, from the locality in which the fossils are best preserved, *the Rousay beds.*

List of the fossils contained in the Rousay beds of Orkney :—

Thursius pholidotus (Traq.), Rousay.
Coccosteus minor (Miller), Rousay, Kirkwall, S. Ronaldshay.
Glyptolepis paucidens (Ag.), Kirkwall, Rousay, Eday, Tankerness, Westray, Sanday, Evie, etc.
Dipterus valencienesii (S. and M.), Kirkwall, Tankerness, Rousay, Eday, Evie, Firth, Westray, Sanday, etc.

Homosteus Milleri (Traq.), Kirkwall, Firth, Rousay, Westray, Sanday, Tankerness.
Cheiracanthus Murchisoni (Ag.), Shapinshay.
Coccosteus decipiens (Ag.), Deerness, Tankerness, Kirkwall, S. Ronaldshay.
Osteolepis macrolepidotus (Ag.), Kirkwall, Deerness.
Diplopterus Agassizi (Traill), Toab.
Estheria membranacea, Kirkwall, Rendall, Westray.
Asterolepis, sp. nov., Holm, Deerness, S. Ronaldshay.

The Stromness Beds.—A careful examination of the list above given will show that not only does it include certain fossils new or rare to Orkney, but that certain others well known to occur there are wanting. It may be said that practically all the fossils in the museums of the world or in private collections which have been furnished by the Orkney flagstones come from a restricted district in the West Mainland, and in the vicinity of the town of Stromness. Here the richness in fossil remains, and their fine preservation, is in striking contrast to the Rousay beds which occupy the remainder of the county. And not only are the fossils more numerous, but species occur which have never been obtained from other districts. Of these, there are two species of Pterychthys—*P. Milleri* (Ag.) and *P. productus* (Ag.)—*Cheirolepis Trailli* (Ag.), *Diplacanthus striatus* (Ag.), and *Gyroptychius angustus* (M'Coy). These, then, in turn constitute the type fossils of still another zone of the Old Red of Orkney, which from the locality of their typical development we will call *the Stromness beds.* With them others occur which are present also in the Rousay beds, viz.—

Coccosteus decipiens (Ag.).
Homosteus Milleri (Traquair).
Dipterus valencienesii (Sedgw. and Murch.).
Osteolepis macrolepidotus (Ag.).
Diplopterus Agassizi (Traill).
Cheiracanthus Murchisoni (Ag.).

No value attaches to these latter as zone fossils, while there can be no doubt that the former, or some of them at any rate, are entitled to this rank. Much remains to be done before the knowledge of the distribution of the various fossil fishes in the Orcadian Old Red Sandstone can be said to be complete, but, from the Stromness beds at any rate, we have the result of seventy years of the activity of collectors, and the main facts must be regarded as already sufficiently established. That in no case have the type fossils of the Rousay beds been obtained in this locality is perfectly certain, and is a striking fact when we remember that the present writer has obtained these species from two localities in other parts of the county (South Ronaldshay and Rousay) in the course of a short space of time; while in no place have the type fossils of the Stromness beds been obtained along with those of the Rousay beds, or, for that matter, in any locality in which, according to the geological structure of the county, these latter are present; and further, as will be subsequently shown, these results, obtained from a study of the distribution of the fossil fishes of Orkney alone, are in substantial

accordance with the facts already known regarding their distribution in the other districts in which they occur. A mutually exclusive occurrence of this nature can only be regarded as due to the disappearance of one series of forms before the arrival or evolution of the other, and clearly establishes that the successive stages of the deposition of the Old Red Sandstone of the Orkneys were accompanied by changes in the fauna which inhabited the waters in which the rocks were being formed.

II.—The Structure of the Orkneys.

I. *Stromness Beds.*

To the geologist who endeavours to unravel the structure of the Orkneys, a magnificent opportunity is afforded by the excellent and numerous coast sections. So completely is the country cut up by sounds and bays, that at no place can there be any doubt as to the general structure; and even in the larger areas of land, as in the West Mainland, wherever cultivation is to be found, dwelling-houses and stone dykes have been built, and one is, as a rule, at no difficulty in finding stone quarries within a comparatively short distance of one another. If we add to these the many opportunities provided by the inland lochs and streams for an examination of the underlying rocks, it will readily be understood how it is possible, in a comparatively short time, to map with satisfactory detail very considerable areas of country. Only in a very few places do superficial accumulations of boulder clay or peat moss conceal the relations of the rocks beneath, through any extensive tract of land. Wherever the flagstones are present, the structure may almost be said to be writ large on the face of the country. As has been frequently observed by writers on the scenery and geology of Orkney, the hills have then markedly terraced contours, the harder beds of flag resisting erosion and forming a terrace, while the softer beds between, by their more rapid decay, form miniature escarpments. These terraces are everywhere present in flagstone districts of Orkney, and to the experienced eye at once reveal the secret of the underlying structure. In some places, as in Rousay and in Westray, they form so noticeable a feature of the landscape, as to remind one at once of the terraced volcanic districts of many parts, both of Eastern and of Western Scotland. That they are preglacial in origin is proved by the glacial striations with which they are often covered,* and no doubt they have suffered during that epoch a considerable amount of rounding and obliteration; their fine development on the west side of Rousay and of Westray is thus a relic of the old preglacial Orcadian landscapes, which owes its preservation to the fact that the ice movement being from east to west, the west side of these hills was spared the intense erosion to which the rest of the country was being subjected.

The Stromness beds of Orkney, although, as a matter of fact, probably the least extensively developed of any of the subdivisions of the lower Old Red Sandstone, have,

* Peach and Horne, *Proc. Roy. Phys. Soc., Edin.*, 1880, p. 3.

curiously enough, received hitherto by far the greatest share of attention. This is due, without doubt, to the number and excellent preservation of their fossils, of which Hugh Miller was led to make the somewhat hyperbolical statement, that were the trade once fairly opened, they could supply with ichthyolites, by the ton and by the shipload, all the museums of the world.* The list of collectors who have searched these beds is a long one, and includes many eminent names,—Hugh Miller, Professor Traill, Mr C. W. Peach, Mr W. Watt of Breckness, the Rev. J. H. Pollexfen, Dr Clouston, to mention only a few of those who, in a previous generation, were the first to develop their palæontological resources. The district to which they are confined is compact and of no great area, lying mostly in the West Mainland, in the parishes of Stromness, Sandwick, Birsay, and Harray. If to this we add the flagstones which unconformably underlie the sandstones of the west end of Hoy, and those also around the granite area in Graemsay, we include the entire district from which have been obtained the many Orkney fossils which are deposited in the museums of the world. The rest of Orkney is a district relatively barren and uninteresting to the collector, with the exception of certain areas of the Eday sandstones, such as Deerness—where, indeed, the abundance of the fossils hardly compensates for the paucity of specific forms.

The granite of Stromness.—Professor Jameson seems to have been the first to recognise the relation between the ancient crystalline rocks of the granite axis of Stromness and the flagstones of Old Red Age which rest on them by means of a thin basal conglomerate. As it has already been more than once described, a brief notice here will suffice. The area occupied is elliptical in shape, and stretches from the Ness of Stromness to the Point of Inganess on the west coast, a distance north-west of about five miles, with a breadth of about a mile. In the hand specimen it is mostly a pink, sometimes a grey granite, of medium grain, and with only a black mica. In many places it is markedly schistose, as at the Ness of Stromness and behind the town, sometimes passing even into a flaggy garnetiferous† mica schist. Numerous veins traverse it, fine-grained elvans and quartz porphyries, with stony matrix and large quartz phenocrysts, and very coarse pegmatites, usually without mica, and showing traces of graphic structure. The microscope shows the rock to be a pretty normal granitite, with orthoclase, plagioclase, and microcline (in small quantities), quartz, biotite, and, especially in the segregation veins, occasional micropegmatite. Sections cut from the gneiss show it to be of similar constitution, but the pressure twinning of the polysynthetic felspars and the strain shadows in the quartz show that in these bands the rock has been subjected to a deforming force.

The basal conglomerates.—Wherever the actual contact between the granite and the flags is exposed, it proves to be an unconformable junction, the rock immediately resting on the granite being always a conglomerate composed of fragments of the crystalline rock. Admirable sections are to be obtained at the Ness of Stromness and

* Hugh Miller, *Footprints of the Creator*, p. 2.

† Heddle, *Geognosy of Scotland*—'Orkney,' p. 135.

at the Point of Inganess. Both have been frequently described, and of the latter locality Professor HEDDLE has given a map. The granite conglomerate is also seen at the Point of Ness, and in the flag quarry at Garson Burn on the Kirkwall road. In no case is it of any considerable thickness, 30 feet being probably the greatest depth anywhere exposed. With it are mixed sandy flags and coarse arkoses, but it is not a little remarkable how soon it gives place to a normal fine-grained dark grey flag, exactly similar to those which cover such wide districts of the county. In fact, such flags are in many places interbedded with layers of a coarse conglomerate. At Yeskenaby, near Inganess, occurs a series of beds of a coarse sandy millstone grit, in which there is a well known quarry for millstones; and though its junction with the granite and conglomerate of Inganess is by means of a small fault, it is easy to see that it is really the rock just overlying the conglomerate let down by this fault against the granite. In fact, on the north-west corner of Inganess, similar beds occur in the cliff where they rest on the granite and granite conglomerate, which form the low shore below. This is in Orkney the only representative of the thick sandstones which elsewhere rest on the basal conglomerate, a fact which strongly supports Sir A. GEIKIE'S opinion that the granite axis of Stromness is a mere local base. Yet the shores on which these fine flags were laid down must have been tranquil and tideless, as deposits so fine could not possibly rest on an exposed or tide-swept shore. The innumerable sun-cracked and ripple-marked surfaces everywhere present in the Orkney flags show that they are the accumulations of a shallow sea, yet they can hardly be regarded as littoral deposits; they were rather the finer sediment of landlocked areas of fresh water, in which the coarser material rapidly sank to the bottom, and was deposited immediately around the river mouths.

The Stromness flags.—The flagstones of the Stromness series encircle this granite and conglomerate, and are beautifully exposed in the magnificent sections of the west coast of the Mainland of Orkney, from the Ness of Stromness to the Brough of Birsay. This most interesting coast has been described by almost every writer on the geology of Orkney. Many of the well known localities for Orcadian fossils occur along this shore (*e.g.*, Rocket House, Breckness, Belyacroo, Ramnageo, Quoyloo). Starting from Stromness we find the rocks have a westerly dip along the shore to Breckness, W.S.W., then along the Black Craig, W.S.W., at Yeskenaby, W.N.W., at Skaill, W. and N.W., and, north of Skaill Bay along Outshore Point to Marwick Head and the Brough of Birsay, about N.W. for almost the whole way. The dips roll somewhat, being S.W., W., and N.W., as is best seen between Inganess and Skaill Bay, but everywhere there is a persistent westerly component. Here we are, in fact, on the west side of a great anticline, which forms the chief structural feature of the West Mainland of Orkney. For about four miles back from the cliff, in all the quarries and burns of Stromness, Sandwick, and Birsay, there is the same universal westward dip. The anticlinal axis runs approximately from Waulkmill Bay in the south to Crustan Point, a mile west of the Brough of Birsay, for to the east of this line, in Firth, Harray, and Evie, easterly dips are consistently

present. The long axis of the Loch of Harray corresponds very closely with the crest of the anticline, as on the different sides of the loch the dips are opposite, and at Brodgar Bridge, at Ness in Harray, and at Dounby we have the flat or gently rolling beds which occupy the summit of the arch. A transverse section of the anticline is exposed on the north coast of the Mainland, from Marwick Head in Birsay to Costa Head in Evie. At Marwick Head the dip is N.W. about 10°, and this continues, with occasional variation and a few small faults, seen in the Bay of Birsay, to Skip Geo, just east of the Brough. Thereafter, along the coast by Crustan to the mouth of Swannay Burn, the rocks lie very flat, with gentle and frequently changing dips, in which, on the whole, those to the east and north-east preponderate. In Costa Head the east dip is persistent, and, gentle at first, constantly increases along the shore line to Burgar, and thence to Aikerness Point in Evie. In this entire and perfect section no disturbance of the flags is anywhere seen sufficient to indicate the existence of a fault of any importance.

If we traverse the Mainland along an east and west line through its centre, the result is the same. Starting at Skaill Bay, we find that the rocks are rolling, but the dips are always westward. Between this and Dounby the low lands are in many places covered with boulder clay, but in all the quarries the dips are west till we arrive within a few yards of the village, where it rolls to north-east. More exposures can be examined by following a line past the Loch of Clumly to the Bridge of Brodgar, which separates the Lochs of Harray and Stenness, as along this line there is an abundance of stone quarries, and the loch shore yields valuable natural sections. At Aith, W., at Sandwick Manse, W. 10° N., at Clumly Loch, W., at Lyking, W. 10° N., finally at Bookan, in one of the most prolific in fossils of all the quarries in Orkney, we have an unbroken chain of west dips, which ends only in the isthmus on which are placed the Standing Stones of Stenness. Along the shore of the Harray Loch, from Voy to Brodgar, the section is very complete, and not quite so simple as the inland exposures would have led us to expect. The rocks which form the Ness of Tenston have indeed a prevalent west dip, but sometimes roll to the east, while reefs of vertical beds run out into the loch in a direction N. 10° W., and everywhere there is much contortion and slickensiding, the organic matter of the dark flags having been deposited as a brightly polished layer on the bedding planes. These are the symptoms which everywhere in Orkney indicate the presence of a considerable fault; and as these broken rocks of Tenston Ness occupy a belt of the breadth of about half a mile, the dislocation can hardly be supposed to be a trivial one. Traced southwards, the same phenomena are to be seen in the rocks around the Bridge of Waithe. From Garson farm, near Stromness, by Bu Point, to the Bridge of Waithe, the rocks are folded into many sharp little anticlines and synclines, with mostly a north and south strike. At the bridge and down the Ireland shore by Cumaness, reefs of vertical slickensided and crushed rock are seen in several places running N. 10° W., and from here along the shore to Houton we have again a continual and rapidly changing succession of little folds (as was remarked by Messrs

Peach and Horne *). Along the shores of the Stenness Loch from Onston to below Deepdale, the same phenomena are repeated. Yet in this district the amount of actual crushing and fracture is much less than on Tenston Ness, and there can be no doubt that the throw of the fault is rapidly diminishing as it passes south. Similarly, to the north, on the shore of the Harray Loch at Kirkness, these appearances are repeated, and no doubt the fault runs northward to the west of Dounby village, though here not easily traceable, owing to the thick boulder clay sheet which covers these low grounds. Here, too, it is dying out, and no trace of it is to be found on the north shore of the Mainland.

Continuing our traverse across this fault, we find that the persistent west dips practically cease at the Standing Stones, where, for a time, the beds are gently rolling, and they are last seen in the quarries to the north-west of Maeshowe. In all Harray the dips are gently eastwards, except on the shore of the loch at the Point of Ness, and these east dips continue through the whole of the range of hills which, starting at Finstown, runs northwards to Costa Hill in Evie, and separates the parishes of Birsay and Harray from Evie, Rendall, and Firth. Similarly, in Greenay Hill, Birsay, in Hunland, and in the hills to the east of the village of Dounby, the easterly dips prevail. It is only in the extreme east of the Mainland, in Woodwick, Evie, in Rendall, and in several places along the shores of Firth Bay, that this direction is reversed, the rocks of this district having in many places a very gentle inclination to the west, and forming thus a little marked syncline.

Such being in its main features the structure of the West Mainland of Orkney, we would naturally expect to find the Sandwick and Stromness beds repeated on the eastern limb of the anticline in Harray and Stenness. This, however, is not the case, as the richly fossiliferous beds on the west side of the Stenness lochs do not reappear on the east, where the rocks in many points resemble the Rousay beds of the North Isles and the East Mainland. They are comparatively poor in fossil remains, and have never yielded, to my knowledge, the type fossils of the Stromness zone. This is, there can be little doubt, the effect of the north and south fault, which has let down these comparatively barren beds against the Stromness series which encircles the granite axis. It is only in the northern part of this area, at Dounby, Greenay Hill, and other localities in Birsay, that the fossils of the Stromness beds are to be found in quarries with an easterly dip, and here the evidence points to the theory that the fault is rapidly dying out, as it passes northwards to the west of Dounby. The Firth and Harray beds may be, in consequence, relegated to the passage beds between the Stromness and the Rousay series of the Old Red of the Orkneys, and seem to be on the same horizon as those which occupy the wide area which stretches from Stenness, through Orphir, into Kirkwall. As we shall see later, when we continue the section through Rousay and Egilshay into the Eday sandstones, we have a constantly ascending succession; and as nowhere do the Stromness fossils recur, the inference is obvious—as might have been anticipated from

* Peach and Horne, *Old Red Sandstone of Orkney*, p. 10

the fact that at Stromness they rest upon the granite axis—that *the Stromness beds form the lowest zone* of the Old Red Sandstone of the Orkneys.

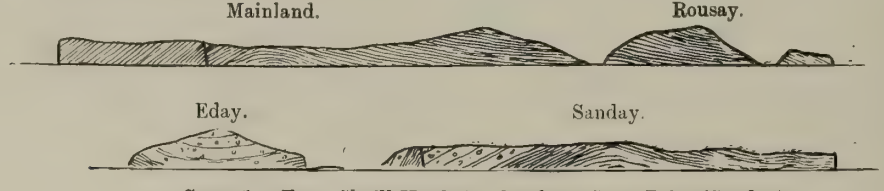
It is a matter of great difficulty to form a reliable estimate of the thickness of this series in Orkney, as will be evident when we consider that its true base is nowhere seen, and that its upper boundary must, in our ignorance of any but the general facts regarding the distribution of fossils throughout the county, be of necessity an arbitrary one. By far the best continuous section of these beds is that exposed along the shore from the Ness of Stromness to Breckness, nearly three miles to the westward. The section runs in a W. or W.N.W. direction, and during its whole course there is a continuous exposure of the rocks at low water. They dip along the shore about W. 10° S., and during the first half of the distance the average amount of dip is 15°. In the little sandy bay beyond the churchyard the dip swings southwards, and is more gentle for a little, but on the west side resumes its previous direction and amount. If we draw a line perpendicular to the strike and measure the distance, it is almost exactly two miles, and the thickness, allowing for an average dip of 12°, is about 2000 feet, which is exactly the thickness estimated by Sir A. Geikie for a section parallel to this and a mile further south, from the centre of Graemsay to the base of the Hoy Hills.* As a matter of fact, as the flagstones at Ness rest on the granite conglomerate, and the rocks at Breckness, if prolonged northwards along their strike, are seen to be on a level not greatly differing from those which at Inganess rest on the west end of the same granite axis, we are led to the conclusion that the western conglomerates must be on a much higher level than those at the east end of the granite outcrop. But the lowest rocks in this district must be those which have been uplifted by the Tenston fault along the axis of the West Mainland anticline. This fault is prolonged southwards through the Bay of Ireland; and if we carry the section backwards from Stromness to Bu Point, we find that along this shore the rocks are so rolling that no great thickness is required to be added to our estimate, the same beds being probably again and again repeated by means of gentle folds.

Results in substantial accordance with this are obtained by taking a section some six miles to the northward, from the fault on Tenston Ness on the Loch of Harray, to Skaill Bay on the west shore of the Mainland. The length of a section from Tenston due west to the Atlantic is nearly four miles, and in the intervening country the dips never vary greatly from a true W. In amount they differ, being 12° or more at Lyking, at Voy nearly flat, at Sandwick manse 5°, at Rango 5°, at Skaill 3 to 7°. If we accept 5° as an average, the thickness is 1760 feet. In this case the conditions are not so satisfactory as in the preceding, the exposure of rock not being a continuous one.

To this must now be added the rocks which lie between those of Breckness and Skaill and the base of the Rousay series. That at both these places we are well within the Stromness zone is evident from the fact that they are among the best known localities for its type fossils. The district in the N.E. corner of the West Mainland

* Sir A. Geikie, *Old Red Sandstone*, pt. i. p. 410.

(Birsay and Evie) will, in my opinion, be found the most suitable for this purpose. If we take a section from Crustan Point in Birsay, the centre of the West Mainland anticline, to Burgar in Evie, where we cannot be far from the level of those beds which in the west of Rousay contain *Thursius pholidotus* (Traq.) and *Coccosteus minor* (Miller), and strike southwards across the narrow Eynhallow Sound, the total distance is five miles, measured across the strike of the beds. The dips throughout are eastwards, and their average amount is about 3°. There is no evidence of any important fault. The thickness must in consequence be about 1300 feet. The exact position of the Crustan beds in the Stromness series is difficult to fix, but, as along the western shore from Skaill Bay by Outshore Point to the Brough of Birsay, the dips are mostly N.W., as we travel northwards the section is a constantly ascending one, and the beds which occupy the centre of the anticline at the northern shore must be far higher in the series than those which occupy a similar position in the neighbourhood of the Harray Loch. The Crustan beds in consequence are, in all probability, on a similar level to those in the vicinity of Skaill Bay; and if we add the lower half of the thickness between Crustan and Burgar to that from Tenston to Skaill, we obtain a total thickness of about 2500 feet for the Stromness beds of Orkney. The beds of Evie may, on the other hand, be relegated to the basal part of the Rousay series, and as yet there is no palæontological evidence to prevent such a step. These passage beds, in fact, between the Stromness and Birsay series below, and the Rousay beds above, are comparatively unfossiliferous, and have yielded little of value to the most careful search.



Sect. 1.—From Skaill Head (Sandwick) to Start Point (Sanday).

II. *The Rousay Beds.*

The Rousay beds of Orkney lie mostly to the north and east of the county, where they cover a much more extensive area than the better known Stromness series. As yet, however, little attention has been paid to them and their fossil contents, and the scarcity and imperfect state of their fossils is indeed disappointing to one who has been accustomed to investigate the West Mainland beds. One may travel for days along the shores or among the quarries on this group of rocks without bringing home more than one or two imperfect specimens. Yet they are never entirely barren, and careful search is always rewarded with recognisable organic remains, usually scattered bones and scales, while in a few places we may find even entire fishes, as perfect in every detail as those which abound in certain of the quarries of Sandwick and Stromness. Very characteristic of these rocks are the scattered bones, the teeth, and sculptured scales of

Glyptolepis paucidens (Ag.), and with it *Homosteus Milleri* (Traq.) is the most abundant fossil,—if we except only the head plates and scattered fragments of *Dipterus valencienesii* (Sedgw. and Murch.). But the last is quite as common, and probably commoner, in the Orcadian beds, while the two former have certainly their principal seat in the beds now to be described. With these a not unfrequent fossil is the little crustacean *Estheria membranacea*, which, as at Thurso, sometimes covers the whole surface of slabs of rocks, and is, so far as I know, confined to this zone. Other fishes occur—*Cheiracanthus*, sp., *Osteolepis macrolepidotus* (Ag.), *Diplopterus Agassizi* (Traill), *Coccosteus decipiens* (Ag.); but their principal development seems to have been in a previous time, as they are much more numerous in the lower series. Of the fishes peculiar to this zone, *Coccosteus minor* (Miller) can hardly be said to be rare, seeing that already we know it in three separate and widely distant localities. It is a very suitable fossil for zonal work, as even its scattered bones are so characteristic as to establish its identity readily. Of the different species of *Thursius*, only one is as yet known to occur; and indeed, until a means is discovered for diagnosing these fishes from scattered head plates, bones, or scales, it is unlikely that they will ever be recognised as common fishes in this region of Orkney. The state of preservation requires, in their case, to be much more perfect than holds good as a rule of the fossils of these rocks.

The North Isles District.

If we now continue eastwards our section through Orkney from Evie, through Rousay and Egilshay (sect. 1), we find that in Eynhallow the east dips which prevail in Evie are repeated, and these beds strike evidently across the narrow Eynhallow Sound into the west side of Rousay. In the latter island the east dips which mark this side of the great West Mainland anticline may be said to prevail throughout, but are everywhere very gentle, and are occasionally subjected to a temporary reversal. The terraced faces of the hills, most marked on the west side, show at a glance the simple structure and the almost horizontal disposition of the beds. Along the western coast, the dips are gentle and frequently changing, being mostly north and north-east in the northern half and south and south-west near Westness, but from Hullion along the south coast to Avalshay the dips are very persistently east, except for a brief space below Trumland House, where a very insignificant anticline occurs. East dips are constant on the shore of Rousay Sound. On the north shore the magnificent range of cliffs from Sacquoy Head to the Knee of Rousay around the whole shore of Saviskail Bay exposes an ideal section, which shows a structure slightly more complicated than that seen on the south side of the island. On Sacquoy Head the dips are east, but on Saviskail Head a small anticline, on the south shore of Saviskail Bay another, and in Scockness a third, throw the rocks into gently undulating folds, whose axis is nearly north and south, without anywhere a dislocation of any importance. The island is thus a geological plateau, out of which the agents of denudation have carved the valleys and modelled the surface features. Its heather-clad

hills are the highest in the North Isles of Orkney, rising to heights of over 800 feet; and if we allow 1000 feet for the total thickness of rock exposed, we have an estimate which cannot be far from the truth. Few fossils are yet known from it: *Dipterus valencienesii* (Sedgw. and Murch.), *Homosteus Milleri* (Traq.), *Glyptolepis paucidens* (Ag.), with the characteristic fossils *Thursius pholidotus* (Traq.) and *Coccosteus minor* (Miller). These latter occur in what are about the lowest beds of the island, a belt of thin blue calcareous flags seen best at Sacquoy Head on the north-west corner, and striking southwards through the island, to outcrop again at the Taing of Tratland and the adjoining shore. At Sacquoy Head they overlie a bed of conglomeratic sandstone, with pebbles up to the size of a walnut, of gneiss and quartzite mostly, and resembling thus the rocks of Heclabir, to be subsequently described. In Egilshay the easterly dip continues, but here much steeper, with evident crushing and fracture of the rocks;* and I think it likely that through this island passes a line of dislocation, evidence of which is to be found in the Galt of Shapinshay to the south, and in the district of Rackwick in Westray to the north, in both of which places the appearances point to a similar disturbance. This would, in fact, be a north and south fault, skirting the Eday syncline, like that already described in the West Mainland anticline, and those also described in several places by Peach and Horne (Sanday, Berstane, Holm).

If the section be now continued across the Westray Firth to Eday, we find, as described by Peach and Horne,† a strip of flagstones, with a very steep easterly dip, ranging from Ferstness to Sealskerry, and bounding on the west the area of the Eday sandstones. These lie in the trough already described by these authors; and, as they showed, the only other flagstone area in the island is one which stretches from Warness to the Graand on the south shore, and thence N.N.E. to the Kirk of Skaill and the inner corner of Backaland Bay on the east side. As the centre of the syncline runs from Zoar in Sealskerry to Calf Sound in the north, these flagstones have a W.N.W. dip of about 15°, and they have been brought up by a small fault against the red sandstones which occupy the south-east corner of the island.

In Sanday the yellow and red sandstones occupy the south-east end, as shown by Prof. Heddle,‡ broken by a fault which, running north and south through Spurness Promontory, brings up again for a brief space the underlying dark grey flags.§ Beyond them, to the north and east, the whole island consists of flags which form a well-marked anticline, their westerly members dipping to the west like the Eday beds, under which they pass, but arching over on the south shore of Otterswick Bay and near Geramont House, so that at Taftsness, Newark, and the Start the prevalent dips are to the east. These Sanday flags yielded little of value to my search, *Glyptolepis paucidens* (Ag.), *Dipterus valencienesii* (Sedgw. and Murch.), with a few well preserved fragments of an Osteolepid fish being all I noticed. There can be no doubt that they are a repetition of

* Noted by Jameson, *Scottish Isles*, ii. 239.

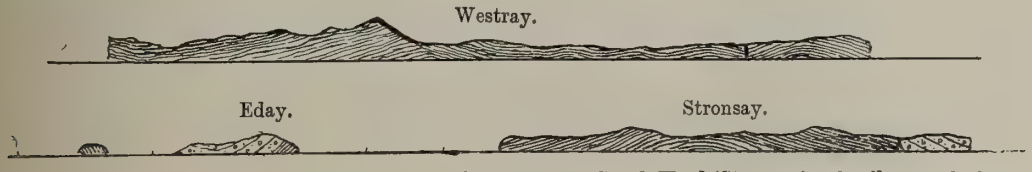
† Peach and Horne, *Old Red Sandstone of Orkney*, pp. 8 and 9.

‡ Heddle, *Geognosy of Scotland*, part v. p. 101.

§ Peach and Horne, *Old Red Sandstone of Orkney*, p. 7.

the Rousay beds on the east side of the Eday syncline, though as yet they have not yielded the characteristic fossils. In the same group must also be placed the North Ronaldshay flags, which time did not permit me to visit and examine in detail. Professor HEDDLE tells us that here the east and west dips are about equally common.* The island of Stronsay, which lies to the south of Sanday, has on the whole a similar structure. It consists for the most part of flags, with one or two areas of John o' Groats sandstones in the south and south-east. The dips along Linga Sound and the north-west side generally are to the north-west, while on the south side, near Housebay, they roll over to the south-east (sect. 2). The structure is thus an anticline like that of the more northern island. I was not able to obtain any data as to the fossils they contain.

In Westray, as PEACH and HORNE† remarked, the structure again is an anticline, though a careful examination showed it was not a simple one (sect. 2). The axis runs from Garth in Tuquoy Bay, to the Sneuk on the north shore. To the west of this, the flags have a persistent though gentle dip to the westward, only reversed for a short space at Noup and Noup Head. To the east of this line the flags form a rolling series, as is well seen along the south shore, where two or three small anticlines and synclines succeed one



SECTION 2.—N.E. and S.W. from Noup Head (Westray) to Lamb Head (Stronsay). 3 miles = 1 inch.

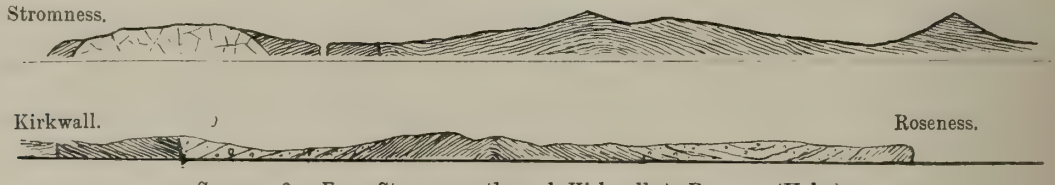
another. On the north shore, the dips are similarly rolling. From the Point of Tafts along the west shore of Rackwick runs a line of dislocation already mentioned as probably a continuation of that seen in Egilshay, and in Rapness the dips are mostly east, though in the extreme south end the flags on the western shore have a west dip. If we neglect the fault, the same strata are thus constantly repeated. There is no doubt they are the same as those of Rousay and of Sanday, the structure being only a continuation northward of that already seen in the northern shore of Rousay. The fossils I found there were *Glyptolepis paucidens* (Ag.), *Homosteus Milleri* (Traq.), *Dipterus valencienesii* (Sedgw. and Murch.), *Osteolepis*? *Estheria membranacea.*

In Shapinshay we have the two series of rocks—the Rousay beds in the north and west, and an area of Eday sandstones in the south and east. On the east side the beds have a strong south-east dip, but on the north-west corner, around the Galt and in Veantrow Bay, the dips roll greatly, and this is probably the effect of a series of faults which disturbs them : one seems to run from the Galt in the north to the Telegraph hut near Elswick on the south, while the fault which starts at Howquoy Head and runs under the town of Kirkwall must pass just to the west of the shore of the island. As has been pointed out by PEACH and HORNE,‡ the area of sandstones on the south-east

* HEDDLE, *op. cit.*, p. 122. † PEACH and HORNE, *op. cit.*, p. 2. ‡ PEACH and HORNE, *op. cit.*, p. 9.

of the island is probably a continuation southward of the rocks which occupy the centre of the Eday syncline, and the eastward dipping flags of Shapinshay will then correspond to those of Egilshay, Ferstness, and Westray, as the west dipping flags in Stronsay correspond with those of Sanday.

As will be evident from this brief summary, the North Isles of Orkney are composed of two members of the Old Red Sandstone—the Rousay beds and the Eday sandstones. The chief structural feature is the Eday syncline. The Rousay beds of Rousay and Westray, dipping eastwards, pass under the sandstones, and emerge again with a westward dip in Sanday and Stronsay, only to roll over again before they finally disappear beneath the waters of the North Sea. The beds which in Rousay contain the type fossils are, in all probability, the lowest of the flags of this area; and although the sections are frequently interrupted by the sounds which separate the islands, and by not a few important faults, it is quite evident that the entire thickness of rock required to explain the geological facts is by no means great. We have already stated 1000 feet as the maximum required for the Rousay flags, and in no other island is so great a thickness exposed. If we add to these the upper half of our estimate for the east side of the Birsay and Evie series, we have a total thickness along this section of not more than 1500 feet. No more than an approximate estimate can possibly be formed in this district, as the sections are so broken up by water, and no recognisable subdivisions can be established, either lithologically or palæontologically, with which we might ascertain the throw of the respective faults.



Section 3.—From Stromness, through Kirkwall, to Roseness (Holm).

The West Mainland District.

Owing to the prevalent north and south strike, the rocks of Rousay may be expected to cross into Evie and Rendall, where they lie in very nearly horizontal but slightly rolling folds, and from here to pass southwards into the district between Finstown and Kirkwall. A similar conclusion is arrived at by the examination of the rocks which stretch eastward from the Bridge of Waithe in Stenness (sect. 3). Here we are among the rolling beds which mark the termination to the south of the fault which runs along the side of the western anticline. These beds are undoubtedly to be placed, with their more northern representatives in Harray, among the upper beds of the Stromness series. Further east in Stenness we find the effects of the western anticline, though here little marked, and evidently dying out. Through most of Stenness and throughout the Ward Hill of Orphir the dips are south-west. The anti-

clinal axis passes almost through Maeshowe down Summersdale into the Kirbuster district of Orphir. In the Heddle Hills of Firth, to the east of this line, the dips are mostly east and north-east, very gentle in the flag quarries, now disused, which crown the hills on both sides of Finstown. From the latter village to Kirkwall we have a rolling succession of gentle anticlines and synclines with axes striking north and south; seen well in the shores of Firth and Kirkwall Bays, where the same beds crop out again and again. There are no steep dips and no traces of any important dislocation, but from Summersdale to Kirkwall, on the whole, the dip is eastward, and we are ascending very gradually in the series. In the quarries to the west of Kirkwall there is a very slight north-west dip, while along the shore to the east of Kirkwall Bay the dips are strongly east. The change is marked by a line of crushed rock which runs under Kirkwall in a N.N.E. direction, and emerges on the shore at Cromwell's Fort. This seems to be the northward continuation of the fault described by Peach and Horne as running from Howquoy Head in Holm, northwards along the shore, and forming the eastern boundary of the sandstones of Scapa Flow.* This may be possibly a continuation of that already described as passing through Egilshay into Westray. At any rate it is an important feature in the structure of this part of the Mainland of Orkney, for to the west of it lie the gently rolling beds described, while to the east the dips are steep as a rule, and the rocks thrown into very pronounced folds. In other words, it forms a natural geological boundary to the East Mainland of Orkney.

The East Mainland District.

The second area in which it has been proved that the Rousay group of fossils occurs in Orkney is that around the town of Kirkwall, in which Hugh Miller remarked their presence more than forty years ago. The structure of the East Mainland has not that simplicity which characterises the West Mainland. To the south-west it is bounded by the fault described by Peach and Horne, which brings down the sandstones of Scapa against the flags. The flags along this fault are probably the lowest rocks exposed, for through the whole area there is a constant tendency to a northerly dip, varied, of course, by the subsidiary folds, and the highest rocks occur only in the northern half of the district. Two series of rocks occur—the Eday sandstones in two areas, Berstane Bay and Deerness, the Rousay beds elsewhere.

The structure is clearly defined, an anticlinal axis occupied by the flags passing up the centre of the district in a north-east direction, and forming the Ness of Tankerness, while on each side a syncline brings in the overlying rocks, the sandstones (sect. 3). The section along the public road from Kirkwall to Dingieshowie, Deerness, affords a very good index to the general structure. For a mile or more after we leave Kirkwall, the rocks are steeply inclined to the east and north-east, disturbed, no doubt, by the great fault whose

* Peach and Horne, *op. cit.*, p. 11.

outcrop we are crossing, and through the promontory between Kirkwall and Inganess Bay the general dip is to the north-east. At the south-west corner of the latter bay the fault already described by PEACH and HORNE, forming the western boundary of this area of John o' Groats beds, is well seen in the shore, letting down the red sandstones sharply against the blue grey flags. These are the flags which in the old quarries at the East Hill, Kirkwall, rather over a mile away, contain the Thurso fossils, according to the observations of HUGH MILLER.* They form a triangular area between two considerable faults; and though in the land north-east dips prevail, as also along the east shore of Kirkwall Bay, along the northern coast from Carness to Meil Bay, a succession of folds repeats them.

Continuing our section eastwards, we find that the sandstones of Inganess dip north-west to the fault, and at their eastern edges are bounded by grey flags with a similar dip. About five miles from Kirkwall, at Quoyburray, in a quarry near the road, the beds lie nearly quite horizontal, and from that point onwards the dips are south-east and generally steep. The axis of the anticline runs approximately from Sebay Mill to the Ness of Tankerness in an E.N.E. direction, as along this north-west shore of Deersound the dips are slight and rolling; and while, to the east of this, at Yinistay Head and through Tankerness we have the north-west dips, in Deerness these have rolled over to the south-east. At Dingieshowie the yellow sandstones are let down by a fault, but maintain the general south-east dip; and from here, along the shore to the Castle, they lie in a little trough, the dips swinging first to east, then to north-east, when they are succeeded by grey flags, which up to Roseness Point have a north dip. Along the shore of Holm Sound the north and north-east dips show that here, too, we are on the south side of a syncline which runs approximately north-east and south-west, but as we pass westwards beyond Graemshall the rocks are much disturbed, and the dips are inconstant and frequently changing.

In spite, then, of their generally steep dips, the flagstones of the East Mainland are so repeated by these folds that they cannot be regarded as of very considerable thickness, and the disturbance to which they have been subjected renders any estimate exceedingly conjectural. Their fossils are few, yet I found in different places *Glyptolepis paucidens* (Ag.), *Dipterus valenciennesii* (Sedgw. and Murch.), *Osteolepis macrolepidotus* (Ag.), *Coccosteus decipiens* (Ag.), and *Diplopterus Agassizi* (Traill).

It is interesting to observe how the section drawn east and west from the Bridge of Waithe to Roseness, through Kirkwall, repeats the main features of that drawn from Skaill Bay to the Start Point of Sanday (sects. 1 and 3). The Tenston fault passes south through Waithe, and the West Mainland anticline is distinctly to be traced in Summersdale, the rolling beds between Finstown and Kirkwall are those of Rendall and Firth, the Rousay beds recur at Kirkwall, and the broken dislocated flagstones to the east of Kirkwall repeat the structure of the west of Shapinshay and Egilshay. The Eday syncline passes south through Shapinshay to Inganess Bay. The anticline of Tanker-

* *Cruise of the Betsy*, p. 394.

ness is that of Sanday and Stronsay, while the sandstones of Deerness and Holm belong to a syncline unrepresented in the northern section, except it be by the limited areas of yellow and red sandstones in the island of Stronsay.

The South Isles District.

South of the Scapa faults not one of these features reappears, and the South Isles of Orkney form a distinct district, with a well-developed structure of its own. It consists of a geological basin, in the centre of which lie the higher beds, the sandstones.* They form the shores of Scapa Flow, from the Old Kirk of Orphir to near Howquoy Head. They reappear in Hunda, the west of Burray, and the north-west of S. Ronaldshay, here dipping west and north-west, and constitute also the north end of Flotta. Around them pass the underlying flags of Orphir, Holm, the east of Burray, the south-east of S. Ronaldshay, Swona, and the south of Flotta. In the north, the junction is a fault; and through South Ronaldshay and Burray it is evident that several faults run north-east and south-west parallel to the strike of the rocks. Yet in some places the succession is an interrupted one, as, for example, to the west of Grimness Head and in the island of Flotta. In Burray the flags dip west, in S. Ronaldshay north-west, in Flotta north, the strike thus sweeping gradually round. Much broken up as the district is by the sea, it is yet sufficiently clear what the general structure of the whole area must be. The Eday syncline is rapidly dying out in Inganess Bay, and I could find no proof that the yellow sandstones pass across the East Mainland near Kirkwall, to unite with those of Scapa Flow. Even should they ultimately prove to be continuous, it is clear that the broad basin of the South Isles cannot fairly be regarded as a continuation of the Eday syncline, which already at the south end of Inganess Bay has narrowed to less than a mile in breadth, and has, furthermore, to cross the powerful dislocation of the east side of Scapa Bay. In all the features of its structure, the South Isles area shows no point of comparison with that around Kirkwall, still less with that of the North Isles of Orkney.

The largest continuous area of these rocks is that of South Ronaldshay, which alone I had time to examine in detail. It consists of two series, the grey flags of the south-eastern district, and the yellow and red sandstones of the north-west. The general dip throughout is N. to N.W., but the structure is by no means simple, as it is evident from the coast sections that powerful dislocations cross the island from N.E. to S.W. On the west side the flags extend from Brough Head to Barswick, much disturbed in many places; and from thence to St Margaret's Hope, and for a mile further east along Water Sound, the shore consists of yellow and red sandstones (faulted apparently in two places at Barswick, where they are brought down against the flags, and at Sandwick). The Hoxa promontory consists of an anticline of blue flags, and is bounded by a fault which runs across the narrow isthmus. On the east shore, again (sect. 4), the dip is continu-

* Peach and Horne, *op. cit.*, p. 12.

ously north, the flagstones stretching from the Old Head to Halcrow Head, whence a small area of sandstones extends to Windwick. Here a fault brings up the flags with a steep north dip, and at Stews Head these again are overlaid by yellow sandstones which stretch along the shore to St Peter's Church, where again the blue flags are faulted up to form the promontory of Grimness and the north-eastern corner of the isle, and to pass conformably into the yellow sandstones along the shores of Water Sound.

Of these rocks the lowest are evidently the flags of Brough Head and Old Head in the southern shore, and here, at Banks Geo, with remains of *Coccosteus decipiens* (Ag.) and of an undetermined osteolepid, I found numerous plates of *Coccosteus minor* (Miller), which have been determined by Dr Traquair. The chief importance of this lies in the fact that it establishes the zonal identity of the flags which encircle the sandstones of Scapa Flow with those which accompany the Eday beds of the North Isles. Here, however, the horizon is, to all appearance, a higher one, as the distance between the *Coccosteus minor* beds and the sandstones of Halcrow Head is not much over a mile; and though there is evidence of faulting in the intervening section, it would seem, as stated by Peach and Horne,* that these faults are not of any great magnitude.

A further interest is lent to the rocks of South Ronaldshay by the occurrence in them of the new species of Asterolepis previously mentioned. Of this I found a plate in a flag quarry on Hest Head. The horizon is that which is, so far as at present known, characteristic of this fish, being in the grey flags about forty feet beneath the base of the Eday sandstones. Another plate of this species was found by Mr Spence of Deerness at the Castle of Claisdie, near Stembuster, in St Andrews, and still another, a year before, by him and myself, a short distance north of Sandside in Deerness. In both these places the geological position is precisely the same; and it seems, in consequence, to be a fish of very restricted vertical range, and may ultimately prove to be the type fossil of a subzone of the Old Red Sandstone of the Orkneys at the top of the Rousay series. That it is to be united with these rather than with the overlying beds is shown by the accompanying fossils, of which the commonest by far is *Dipterus valencienesii* (Sedgw. and Murch.), which occurs often in very great numbers in this particular belt of rock. Remains of osteolepid fishes also occur, but there is no trace of the distinctive fauna of the Eday sandstones.

Lithology of the Flagstones.

When we pass from an examination of their fossil contents to the study of the rocks themselves, at first glance we are apt to be greatly impressed by their monotony, and the endless repetition of beds in no way differing greatly from one another. The effect on Professor Jameson we have already mentioned: his six weeks' journey in Orkney proved the most uninteresting he had ever made. The geologist who is bent on the search for easily recognisable lithological zones which can assist him in the completion of his map is sure to suffer a like disappointment. Immense as is the variety in these beds, no

* Peach and Horne, *op. cit.*, p. 11.

two being in every respect similar, there are yet no recognisable and definite alternations which could with certainty be used in dividing up the whole into an established succession. This is true of the Orkney flags as a whole, as was pointed out by Messrs Peach and Horne. They vary greatly, the principal types being a sandy flag, a clay flag or mudstone, and a brittle calcareous or even bituminous flag. The sandy flags never amount to pure sandstones, there being always a certain amount of clay and of silky weathered and bleached mica, with very usually a calcareous cement between the grains of sand. The clay flag is the purest and most abundant type. They are relatively soft, fine-grained, and light grey in colour, except when darkened by organic material. On their bedding planes the pale lustrous mica is often to be seen as a shimmering film, while the microscope shows that in worn, tattered, and crumpled flakes it is an important constituent of their mass. Sand in fine rounded grains and calcite in greater or less abundance are constant constituents. Where these softer beds occur mixed with harder beds on a cliff face, they weather out rapidly into pale grey hollows, and this is the origin of a frequently remarked feature of the Orcadian cliff scenery. The calcareous and bituminous flags are the chief receptacles of the fossil remains inclosed in these rocks. The fossil collector very soon learns that the best specimens are obtained in a brittle, hard, usually slaty and thin-bedded rock, which rings to the hammer like a piece of metal. This is in some measure due to the compactness and impermeability which is conferred on these rocks by their abundant calcareous matter. But there can be no doubt that, in turn, the presence of the organic remains facilitates in some way the accumulation of carbonate of lime in the rock, as frequently around the fossil is a well marked nodule, compact and hard, and evidently calcareous in nature from the rapidity with which it weathers out, leaving the surrounding rock comparatively unaffected. These are especially common in the dark flags among the sandstones of the Eday series. The prevalent colour of these calcareous flags is dark blue-grey, and they are fine-grained, and mostly free from the concretions so abundant in the more argillaceous rocks. In these latter they are so common that hardly a stone could be found without some trace of them. Of all sizes, from that of a melon to less than a pea, and of a remarkable and often grotesque variety of shapes, they show most clearly in the weathered face of an old dry-stone dyke, or on the bare surface at the edge of the high cliffs of the coast. From the manner in which they resist the weather, they are in most cases probably siliceous—they are certainly harder and more difficult to break than the rock surrounding them. Of these concretions the best known example is the horse-tooth rock of Yeskenaby, to which Professor Heddle* and other authors have devoted some attention. The rock itself occurs *in situ* at Borwick, near the great trap dyke there. But this is merely an interesting variety of a phenomenon of universal distribution throughout these flags. Their surfaces are often mottled and pitted with innumerable little concretions, which it would be easy to mistake for coprolites or for rain pittings. Not uncommonly these consist of pyrites and of marcasite, which on

* Heddle, *op. cit.*, pl. xiv.

weathering give a rusty colour to the surrounding rock. When the flagstones weather, the siliceous concretions, owing to their greater durability, stand out in high relief upon the bedding planes, and give the rock often a curiously fretted and ornamented appearance, and so numerous are they that frequently they resemble a solid mass of fretwork or of repousée ornament upon the surface of the stone. On weathering the flags lose also their prevalent pale or dark grey colours. Many of the dark calcareous flags around Stromness weather with a creamy yellow crust, which resembles that of certain impure carboniferous limestones. Yellow and different shades of brown are the prevalent tints of the weathered stone. The changes are principally the removal of the lime in solution and the oxidation and hydration of the iron. It is the latter which stains the rock, as is seen when we consider the source of the white colour which marks the weathered flags in a peat bed, and which is due to the organic acids of the peat having removed the iron from the rock. The decomposition gradually proceeding inward from the surfaces and cracks, produces sometimes a curious effect on a seashore where a bed of calcareous flag is divided up by many joints into polygonal areas, around the outside of which is a soft, rusty, decomposed film, an inch or more in depth, while the centre area is hard, grey, and comparatively fresh. The innumerable sun-cracked and rippled surfaces were well described by Sir A. Geikie * in the flags around Thurso.

In thickness the beds vary from an inch up to perhaps 18 inches. In every district of Orkney, flags of 2 or 3 inches thick and in large flags can be obtained for paving purposes. A favourite kind at present is a coarse sandy flag in thick beds (6 inches), obtained from Orphir. Thinner slabs, used formerly for roofing slates, are also of very wide distribution. The thick beds are valued for building purposes, especially if the bedding planes are smooth and the joints well marked. In the latter case they need no dressing, as the builder places the smooth joint face, often covered with a fine layer of glancing calcite, to the outside of the wall. In some places a variety of flag occurs, very dark in colour and seemingly much crumpled, the minute laminæ of which it consists being contorted in every conceivable fashion. Such beds are of restricted distribution, and usually markedly lenticular, as they thin out abruptly in no great distance. They bear a superficial resemblance to certain curly oil shales in the Edinburgh district, but when broken open they consist of an ordinary grey flag, the contorted layers being often covered with a dark film. They are not due to earth movement and crushing, as they occur in perfectly undisturbed rocks, and they probably result from peculiar conditions of deposit, perhaps the escape of gases or the decomposition of organic matter having produced their irregular internal structure. Where the flags are crossed by a fault the disturbance is often very great, and quite out of proportion to the magnitude of the dislocation. The rocks are bent and twisted, their surfaces slickensided and blackened, or a dark breccia produced, in which the flagstone particles glance with organic matter till they resemble broken bits of coal. In some cases the fault is marked by a layer of crushed rock powder, intensely black in colour, and mixed with calcite and iron pyrites.

* Sir A. Geikie, "Old Red Sandstone," *Trans. Roy. Soc. Edin.*, vol. xxviii. p. 393.

The peculiar nature of this flagstone deposit is so strikingly new to the geologist accustomed to the study of other districts that it cannot fail to suggest a consideration of the question of its origin. Sir Archibald Geikie * has insisted strongly on the marked difference between these and the sandstones which in other parts of Scotland are so characteristic of the Old Red. This striking contrast in the nature of the strata points to markedly dissimilar conditions of deposit. As we trace upwards the Old Red Sandstone of the Orkneys, we shall see that in process of time this type of sediment was replaced by the more familiar one of yellow and red sandstones and red marls. There can be no doubt that this was the result of marked changes in the physical geography of the region; and when we remember that at Cromarty beds of yellow sandstone contain precisely the fossils of the flagstone beds around Stromness, and, beyond reasonable doubt, were being formed at the same time, we see clearly the truth of Sir A. Geikie's conclusion that the flagstones of Orkney are merely the result of certain peculiar conditions of deposit. From their rippled and sun-cracked surfaces, they were certainly originally laid down in shallow water; and from the extensive area they now occupy, they must in many cases have been laid down far from land. That this area was tranquil I have shown to be probable, from the way the fine flags lie among the conglomerates of Stromness right against the old granitic shore. A similar mixture of deposits is to be found at the present day only in the land-locked areas of our river mouths and inland lochs. The other striking feature of these flags is the way in which they combine materials in other formations confined to different rocks. All contain sand, clay, and carbonate of lime in varied proportions, yet sandstones, limestones, or true shales are never typically developed in this peculiar formation.

III. *The Eday Sandstones, or John o' Groats Series.*

The Rousay beds of Orkney, as described by many previous writers, pass upwards conformably into an overlying series of yellow and red sandstones and marls, which contain in many places the fossils which characterise the John o' Groats beds of Caithness, and are to be regarded as on the same horizon with them. This is a very different series, and much more varied than the Rousay beds of Orkney. An entire change in the nature of the sedimentary deposits indicates a complete and comparatively rapid change in the physical conditions of the area. The yellow sandstones, with their flag beds grading upwards into red sandstones and marls, must have been the formation of shallow areas of water, with currents sufficiently strong to introduce now and then even layers of coarse gravel. The unvarying and monotonous Rousay beds, the deposit of still, though comparatively shallow water, come suddenly to an end. It is interesting to observe that these changes were accompanied by the outburst of volcanic action in a district which had for ages been the seat of uninterrupted quiet sedimentation. In the whole thickness of the Stromness and Rousay beds of Orkney there is no trace of

* Sir A. Geikie, "Old Red Sandstone," p. 363.

contemporaneous volcanic activity. The same conditions prevailed in the Thurso area, as was shown by Sir A. Geikie, the first trace of volcanic rocks being the necks on the shore at Huna, which pierce the red beds of the John o' Groats sandstones.* These physical changes heralded also the appearance of a completely new fauna in the district. It is long since it was shown by the late C. W. Peach that at John o' Groats occurred certain fossils nowhere else to be found, viz., *Tristichopterus alatus* (Egert.) and *Microbracheus Dicki* (Traq.),† and to these *Dipterus macropterus* (Traq.) was subsequently added‡ by Dr Traquair. The same species occur in Orkney, as I have elsewhere shown, and here they form practically the only known fossils of these beds. With the single exception of a specimen of *Coccosteus decipiens* (Ag.) collected in Newark Bay, Deerness, by Mr Magnus Spence, and forwarded by him to Dr Traquair, I know of no other fossils which have been found in them. How sudden and complete the change must have been is shown by the following facts. In Eday, *Glyptolepis paucidens* (Ag.) and *Dipterus valencienesii* (Sedgw. and Murch.) occur within a few feet of the base of the yellow sandstones. In the Deerness district *Asterolepis*, sp. nov., *Osteolepis macrolepidotus* (Ag.), *Dipterus valencienesii* (Sedgw. and Murch.), *Glyptolepis paucidens* (Ag.), and *Coccosteus decipiens* (Ag.) occur in the rocks immediately underlying these beds, *Dipterus valencienesii* (Sedgw. and Murch.) in some places in vast numbers and curiously small in size. With the single exception already mentioned, not one recurs in the richly fossiliferous flags among the yellow sandstones. It would seem as if these species had been unsuited to the new environment in some manner or other, and their extinction had been rapid and complete. The flags so crowded with remains of *Dipterus valencienesii*, only a few of which have attained their full size, irresistibly impress on the mind the idea of a sudden extermination. At a higher level we find the same confused aggregation of fishes in the flagstone belts among the yellow sandstones, but this is on the horizon of the volcanic rocks, and we shall probably be right in regarding it as a consequence of the volcanic activity. The rocks of this series, unlike those they overlie, fall perfectly naturally into two main subdivisions, a yellow below and a red above, the latter possibly an index to the change which ensued on a contraction of the area of the old lake, and rendered it the seat of chemical operations resulting in a new type of deposit.

In their paper on the Old Red Sandstone of Orkney, Messrs Peach and Horne described with great accuracy the boundaries of these rocks, which they named the 'upper sandstone series' of the lower Old Red. It will be sufficient if I here give merely a brief account of their distribution. They occur in the centre of the Eday syncline, forming most of the island of Eday and the Red Holm between it and Westray, and lying in a gentle syncline, which is broken by a fault bringing up a strip of flags which stretches from Warness to the Kirk of Skaill. As described by these authors, the

* Sir A. Geikie, *Old Red Sandstone*, pt. i. p. 405.

† British Association Meeting at Aberdeen, 1858.

‡ Egerton, Geological Survey Decade. Traquair, *Geological Magazine*, Nov. 1888. *Proc. Roy. Phys. Soc. Edin.*, 1896.

succession between the lower and the upper series is a perfectly conformable one. An extension of this syncline occupies Spurness, the S.W. corner of Sanday, and the Calf of Eday. It stretches southwards into Shapinshay, where it forms the south-east corner of the island. These beds have mostly a south-east dip, and belong to the west edge of the syncline. Thence it extends into the opposite shores of the Mainland, and occupies an area which stretches from Holland Head around the shores of Inganess Bay and in a narrow strip to the Skerry of Yinistay in Tankerness. The west boundary of this is a considerable fault already described as seen in the south-west corner of the bay, on the old Kirkwall road, and running thence along the shore and by Berstane House to the centre of the Bay of Meil. On the eastern boundary the sandstones pass perfectly conformably downwards into the flags.

The second area of these rocks is that of Deerness, first described by the present writer in a previous paper. It is separated by the Tankerness anticline from the Inganess Bay area, and the Rousay flags appear on the west corner of Deerness, near Mirkady, and pass up conformably into the John o' Groats beds. The whole area forms a well marked syncline, which includes almost the whole of Deerness, and stretches thence into Holm, where a narrow area of these rocks surround the farm of Stembuster. The dips throughout the south-east half of the sandstones of Deerness are south and south-east. At Stembuster the south-east dips gradually swing round to E.N.E., and finally to nearly north, near the Castle of Claisdie. Several faults occur in the area, one at the Mull head letting down the red and yellow sandstones against the grey flags, which at Sandside contain *Asterolepis*, sp. nov., and *Dipterus valencienesii* (Sedgw. and Murch.), but none of the John o' Groats fossils. These flags in turn, as we pass southwards, graduate upwards into the yellow sandstones. Another fault must run into Newark Bay (though not seen, the area being occupied by blown sand), for to the east of it the dips are south, while to the west the dips are mostly E.S.E., and the yellow sandstones of one side strike at the red beds on the other. Much of this syncline must lie out to sea, and possibly, as already suggested, the red rocks of Stronsay are really part of it, though it is worth mentioning that the rocks of Copinshay are grey flags, undoubtedly belonging to a lower horizon.

In the south isles of Orkney the sandstones occupy the centre of the basin.* A narrow strip of sandstones bound Scapa Bay from Orphir Kirk to near Scapa Distillery and thence along the eastern shore to Howquoy Head, in Holm. They form the west end of Rousay and the island of Hunda, here dipping west, the north-west corner of South Ronaldshay, with a general north-west dip; and on the east side, at Windwick and St Peter's Church, small areas of sandstones are faulted down among the flags of the south and east side of the island. In Flotta they occupy principally the northern half of the island and the adjacent Calf of Flotta, having here a north dip, and passing down conformably into the grey flags of the southern shore.† Lastly, in the island of Hoy they are found in that part of Walls to the north of Longhope, around the Burn of Ore,

* Peach and Horne, *op. cit.*, pp. 11 and 12.

† Peach and Horne, *op. cit.*, p. 12.

and are separated by a fault by the upper Old Red Sandstone, which extends over the most of the remainder of the island.

The Yellow Sandstones and Flags of the John o' Groats Series.

Starting at the northern extremity of their area in Orkney, we find that in Eday these beds occupy a comparatively small area and are of very limited development. At the Kirk of Skaill, on the eastern shore of Eday, a belt of yellow sandstones immediately overlies the top flags of the Rousay series. These are followed by a thin zone of red marls, which in turn are overlaid by thin-bedded calcareous flags, rich in fossil remains, of which *Dipterus macropterus* was the only one I found in satisfactory preservation. Above these we find a series of yellow and red beds (with thin layers of conglomerate), which form a gradual transition to the red and brown sandstones and marls so largely developed in the centre and north end of the island. The whole thickness of this series is not over 100 feet, and it is, in fact, their most insignificant development in any part of Orkney. Were it not for the very convincing sections elsewhere obtained, it would be impossible to regard these beds as other than a merely local facies of the basal series of the red beds. Messrs Peach and Horne* give the following estimated thickness :—

Red and yellow sandstones—
Flagstones, 40 feet.
Reddest shales, 15 feet.
Hard white sandstone, 20 feet.
Gray calcareous flagstones.

—the last being the underlying Rousay series, as I regard them, as they contain no trace of John o' Groats fossils of the group of flagstones interbedded with the sandstones, while *Dipterus valencienesii* and *Glyptolepis paucidens* are not infrequent in them. These yellow beds and flags stretch across London Bay, and emerge again at Millbounds, where the section is very similar to that described.

On the west side of the syncline the same beds crop out again just to the east of Fersness, where they furnish the chief supply of yellow freestone used for building purposes in Kirkwall and throughout the islands. A hundred yards to the east of the pier the yellow beds come in gradually below the red, which here dip about E.S.E. Among them occur again a belt of thin flags and an insignificant red series. The section, in fact, repeats in every respect that to the east, and *D. macropterus* is found in the flags to the west of the pier, but here the thickness must be somewhat greater, as the average dip is about 20°, and the area of shore occupied is about 400 yards. At Warness, again, to the south-west corner of the island, the underlying flags, with here and there a yellow bed, pass up into a yellow sandstone series, 70 to 80 feet thick, over-

* Peach and Horne, *op. cit.*, p. 5.

laid by a few feet of red beds, and these by 20 feet of coarse flags (in which I found no fossils). Over these flags, which no doubt are the same as those of London Bay, come a few yellow beds, which rapidly give place to the red sandstones of Sealskerry Bay.

In the south end of Sanday these beds recur, and form the western edge of the promontory of Spurness, disturbed and set on end by a north and south fault, which brings up with them the underlying beds of flagstones in a narrow strip. A thick conglomerate occurs among them at Heclabir, but in other respects they differ little from the Eday sandstones, though, from their limited distribution, no very complete idea of their features can be formed. After we cross the fault above mentioned, we find the red sandstones in great strength, forming the shore to near the Noust of Boloquoy on the north coast. Here yellow and red beds, mixed, strike along the shore, and, slightly faulted at Grunnavi Head, continue with a dip W.N.W. to Blue Geo, where the flags again come in. The thickness here is not great; but owing to the presence of several small faults, an exact estimate is not possible. These beds, traced along the strike, emerge at Quoyness on the south shore, where, however, they are covered by the blown sand of the beach. The yellow sandstones of Sanday show the same features as those of Eday, and, like them, are of comparatively small thickness.

The conglomerates which occur in these rocks of Eday and Sanday have already been the subject of discussion by several writers.* Professor Heddle noted that at Heclabir, in Sanday, occurred a bed of conglomerate about 14 feet in thickness, and that the pebbles it contained consisted of "granites, more than one variety, gneisses, often chloritic, porphyrys, and seemingly of quartzite,—rocks which are entirely different from the primitive rocks near Stromness, and therefore rocks not occurring in the islands."† He states also that both the pebbles and the cementing paste have a highly vitrified aspect, and that he had a strong impression this was a volcanic conglomerate. Messrs Peach and Horne state with regard to the beds of Eday, which form very insignificant belts at the base of the red series—nowhere over a few inches in thickness—that "the included pebbles consist of fragments of mica schist, quartzite, gneiss, granite, and other metamorphic rocks, all stained of a reddish colour."‡ According to my own observations, all those mentioned occur with one exception; the commonest by far at Heclabir being a creamy or white lustrous quartzite, in much rounded and waterworn pebbles, up to 6 inches in diameter. At the latter locality I was unable to find any volcanic rocks, but there were very numerous pebbles of grey limestone, which microscopic sections showed to be entirely holo-crystalline and true marbles, without any trace of organic structure. With these were others which at first puzzled me; but on referring to Mr Peach, he at once recognised them as cherts and cherty limestones from the Eillean Dhu series of Durness (Cambrian); and the microscope showed that, like these, they were of oolitic structure, though, so far as my examination went, by no means so perfect as in the

* Jameson, *Mineralogy of the Scottish Isles*, vol. ii. p. 257.
† Heddle, *Geognosy of Scotland*, v. p. 103.
‡ Peach and Horne, *op. cit.*, p. 5.

sections shown me by Mr PEACH. By his advice I searched carefully, on a subsequent visit to the spot, for traces of the piped quartzites and other Cambrian rocks, but failed to observe any. The presence of these pebble beds shows very clearly how great must have been the physical changes which the area had undergone, before sediment so coarse reached districts which had long been the seat of a deposit of the finest grain and the most uniform nature. They are very local in distribution, no trace of the thick beds at Heclabir being found among the yellow sandstones in other areas of Sanday, or indeed anywhere in the district, except on the opposite shore of Eday, where their thickness is quite trivial in comparison.

The yellow beds of Eday and Sanday stretch southward into Shapinshay, where they attain a much greater importance, forming, in fact, the whole thickness of the John o' Groats series in that island. Here the outcrop forms the south-east corner, and is bounded by a line running N.E. from the angle of the bay below the Established Church on the south shore to the Bay of Crook on the east. The underlying flags seem to pass up quite conformably and without any important break into a series of yellow current-bedded sandstones, mixed with numerous thin beds of dark-coloured flags. Along the east side the structure is simplest, the prevalent dips being S.E. and E.S.E., but elsewhere the dips roll greatly, and the beds are evidently being constantly repeated. The yellow sandstones overlying these mixed beds are very pure and massive, and cannot, with any probability, be estimated at less than 400 to 500 feet. Only very rarely is a red-coloured bed of clay to be seen; but at more than one place there occur belts of flags intercalated between yellow sandstones, and in some places 30 feet in thickness. These flags may be the counterparts in this area of the flagstones which in Eday occupy a similar position, and, like them, they contain the characteristic John o' Groats fossils, one specimen of *Tristichopterus alatus* (Egert.) having been found by me at Store Point in a coarse grey flag. It is among them also that the volcanic rocks * occur which PEACH and HORNE described as the only evidence of contemporaneous volcanic action in the lower Old Red of Orkney. They consist of a single lava flow, which, though much weathered, is recognisable as an olivine diabase, and is distinctly vesicular at the top surface, while it rests quite conformably on the underlying flag, which is considerably baked and altered.† To their observations I have only a few to add. The interbedded character of the volcanic rock is shown also by the occurrence at its south-western corner of a bed of ash several inches thick immediately overlying it, while in several places thin layers of sprinkled ash can be traced in the overlying flags a few inches apart, and to a distance of 10 feet above the surface of the lava. This shows that though the volcanic activity resulted apparently in only one outflow of lava, it continued for a time to produce occasional showers of ashes, which were spread out over the sea-bottom, and mixed with the sediment accumulating there. At its base the lava contains here and there a bit of an angular baked flag, but its upper surface is vesicular

* JAMESON, *Mineralogy of the Scottish Islands*, ii. 235.

† PEACH and HORNE, *op. cit.*, pp. 9 and 13.

and very irregular, the sandstone filling up all these irregularities quite unaltered and undisturbed in bedding. In several places the lava is 30 feet thick, but in one little creek its top and bottom surfaces were seen in section, and here it was not over 12 feet in thickness. Its greatest development is to the south and east, from which direction it seems to have flowed from a source now, no doubt, concealed by the sea; and this conclusion is strengthened by the occurrence on the same horizon of similar volcanic rocks in the sandstones of Deerness.

The southern termination of this area of John o' Groats beds corresponds very closely with the shores of Inganess Bay. At more than one place in this district the flagstones have yielded *Dipterus macropterus* (Traq.) and *Tristichopterus alatus* (Egert.), and in it occur both types of sediment characteristic of these rocks; but so completely is it occupied by the sea that little certainty can be attained as to its exact geological structure. Along the eastern shores the rocks are yellow sandstones, with many thin beds of dark brittle flag, dipping mostly N.W. at gentle angles. On its western side, again, the red sandstones and marls of Holland Head are underlain by a fine pure yellow sandstone below Berstane House, which at its lower part contains belts of flagstone, and even an occasional red bed. The proximity to the great fault which runs out to sea in Meil Bay disturbs these rocks somewhat, but there can be no doubt that this is the order of the succession, and that, on the whole, these are higher in the series than the yellow sandstones, which on the other side of the bay rest on the flags of the East Mainland anticline. The area must be somewhat disturbed by faults, for on the shore to the southward, at the west corner of Inganess Bay, we find a patch of red marls which belong undoubtedly to the overlying red series. The yellow sandstones of this area bear a close resemblance to those of Shapinshay, from which they differ chiefly in the absence of any interbedded volcanic rocks. They show also that the Shapinshay rocks are merely the basal part of the series, and that overlying the yellow beds in this area, as in Eday, there is a series of red sandstones and marls of considerable thickness.

In Deerness occurs an area of John o' Groats beds which in some respects is the most varied and interesting of any in Orkney. Separated from the previous series by the anticline which brings up the lower flags through the parish of St Andrews, it forms in turn a syncline or basin, of which only the northern half is accessible to observation. The axis of this syncline runs probably E.N.E. from Stembuster on the shore south of Dingieshowie, and on the south side of this axis we have only a very short stretch of sandstones along the shore to just south of the Castle of Claisdie, where they pass down into the grey flags of the parish of Holm. Northwards along the shore the dips sweep round, till at Dingieshowie they are E.S.E.; and E.S.E. and S.E. dips, as already remarked, are far the most prevalent throughout the parish of Deerness. One of the most complete and trustworthy sections is that described by me in a previous paper * as stretching from Dingieshowie to Newark Bay along the south shore, but this is in so far incom-

* *Trans. Roy. Phys. Soc. Edin.*, vol. xiii.

plete that the fault which crosses the isthmus at Dingieshowie cuts out the passage beds underlying the yellow sandstones. These are seen in the shores farther west, at Stembuster, where they consist of thin courses of yellow sandstone with slaty flags between, forming a very gradual transition between the two types of sediment. Above these 'passage beds' lies a series of red marls, with thin yellow and brown sandstones (40 feet) between, recalling in some ways the beds described as occupying a similar position in Eday. The exact point at which the base of this series should be drawn is a matter of some doubt, as among the lowest of them occur beds crowded with *Dipterus valenciennesii* (Sedgw. and Murch.), and containing also *Asterolepis*, sp. nov., but containing no other fishes, an observation due to Mr Magnus Spence. Traced upwards, the red beds pass gradually into a pure massive yellow sandstone, which forms the high cliff below Tornpike, and is, no doubt, the same as that of Delday's Banks. These lowest beds are exposed also in other parts of the parish, as at Braebuster and the shores to the south of it, where thin grey flags pass gradually up into yellow sandstones. In the north shore of Deerness a very similar series occurs at Halle, and extend thence to near the Covenanters Monument, lying very flat, and forming the extreme N. edge of the syncline; and these rocks must again outcrop in Sandside Bay, between the flags which form its northern side and the yellow sandstones to the south, though here the rock is concealed by the blown sand which occupies the centre of the bay. Just north of the Brough of Deerness the presence of a few red beds beneath the yellow sandstones is well seen in a lofty cliff, and again the same feature is to be observed in the shore below Horraquoy. The yellow sandstones recall, in very many respects, those of Shapinshay. They are of much the same thickness, 400 to 500 feet, and through them lie here and there belts of thin grey calcareous flags, which are the chief source of the John o' Groats fossils of Orkney. They contain *Dipterus macropterus* (Traq.), *Tristichopterus alatus* (Egert.), and *Microbrachius Dicki* (Traq.), the first especially in great abundance, and often in fine preservation; and it is probable that through the low lying centre of the parish these largely replace the yellow sandstone series.

A further point of similarity to the yellow sandstones of Shapinshay is furnished by the presence in these beds of a zone of contemporaneous volcanic rocks of basic composition. These occur rather above the middle of the yellow series, and, as in the district previously described, they are immediately associated with a belt of grey flags intercalated among the sandstones. They consist of both ashes and lavas, and in addition there are several intrusive sheets which, from their composition and general character, are undoubtedly to be ascribed to the same volcanic source.

At the extreme south-east corner of the parish, at the Point of Ayre, a series of volcanic rocks form a narrow belt running W.N.W. in the land, and outcropping on the seashore. The general dip in this quarter is S. and S.S.E., and from Horraquoy southward along the east shore we pass over a gradually ascending section of the lower members of the yellow sandstones. This dip continues to the Point of Ayre, which consists of beds of flagstone, and these, though somewhat faulted, evidently are to be

assigned to the upper part of the yellow beds. From this point westward they strike along the shore, which they form up to the Bay of Newark, where they are covered by blown sand. On the west side of the bay, beds occur striking N.N.E., and evidently let down by means of a dislocation covered by the superficial accumulations in the centre of the bay. The principal mass of volcanic rock at the Point of Ayre forms a narrow area which runs E.S.E. out to sea, and is in breadth about 40 yards. Its base is not seen, and its lower member is a thick bed of dark green volcanic ash, with large spherical bombs up to 2 feet in diameter, vesicular, especially in the centre, and much decomposed. A few bits of baked flag occur in the ash, and it weathers in a markedly spheroidal manner, resembling, in fact, very closely many of the basaltic ash beds around the shores of the Firth of Forth, as at Kinghorn and Elie. In general it shows no trace of bedding, but here and there a few thin irregular lenticles of sand are to be seen, which prove that though rapidly accumulated, it is not the product of a single outburst. A curious feature is the existence in it of flagstone veins. These are very tortuous and irregular, an inch or two in thickness, and filled with a normal, somewhat calcareous flagstone, in which little or no trace of any metamorphism is to be found. They are vertical, and show no sign of bedding or contortion, and are to be regarded as due to the formation of cracks in the thick accumulation of volcanic ash, into which the ordinary sediment of the sea-bottom was washed. At first glance, this bed of agglomerate suggests at once that it is a volcanic neck, and the elongated form of its outcrop would support this explanation. But its junction with the flags to the south is a small fault, and these show none of that alteration which is to be expected in the walls of a volcanic neck. And, moreover, the bed itself is seen in the low cliff to be overlaid by a thin lava, and that again by well-bedded flags. Still, it is in every way probable that an accumulation of this sort was formed in the immediate proximity of a volcanic orifice. The overlying lava is some three feet in greatest thickness, vesicular at its upper surface, the vesicles being large, not markedly elongated, and filled with calcite and other secondary minerals. It is greatly decomposed, but shows little of the spheroidal weathering of the agglomerate, being rather divided by well-marked joints into polygonal vertical columns. Under the microscope it turns out to be an olivine basalt, so greatly decomposed that few of the original minerals remain. At the western corner of the outcrop this lava is seen to be, in turn, overlaid by ordinary flags, which are in nowise altered by the heat of the underlying rock, and contain little or no fragmental volcanic matter. These rocks are bounded to the south, and probably also to the north, by small faults. A few yards to the west of them, what seems to be a quite distinct outflow is exposed in the shore. This is the edge of a small lava flow, three feet in thickness, and thinning out in a few yards to the south, while the flags close over it. It is dark in colour, with large steam cavities in its upper surface, and bears a striking resemblance to the volcanic rock at Haco's Ness, Shapinshay. The sea has removed the overlying rocks, except at the thin edge, where a layer of dark green ashes mixed with sand is seen to immediately overlie the lava, succeeded in turn by a normal unbaked ordinary flag. The lava rests upon a similar

flagstone, and hence cannot be the same as that already described to overlie the thick agglomerate bed, a few yards further to the east.

Among the yellow sandstones, about two miles further to the west along the shore, and about a hundred feet below where they pass into the red sandstones, occurs another belt of contemporaneous volcanic rock. It is associated here, also, with a series of flagstones, and no doubt is on the same level as the rocks just described. In a little bay to the east of the Castle, a bed of dark green ashy sandstones, mostly fine-grained, but with here and there lapilli of a couple of inches in diameter, is to be seen, interbedded with yellow sandstones and flags. It is very similar in character to the ash beds in Shapinshay which overlie the lava; but while these are mostly of very inconsiderable thickness, it is in some places three or four feet thick. No lava is associated with it, and in the sandstones above and below I found no trace of any recurrence of the volcanic activity. In all probability it is the representative, in this section, of the coarse agglomerate already described, which must have greatly thinned out in the intervening distance. The striking feature of this volcanic zone is its very diminutive thickness. Still, the occurrence in Orkney of such a zone is a remarkable confirmation of the opinion expressed by Sir A. Geikie, that the "ancient volcano of John o' Groats might be one of a series which might hopefully be sought for among the Orkney Islands." *

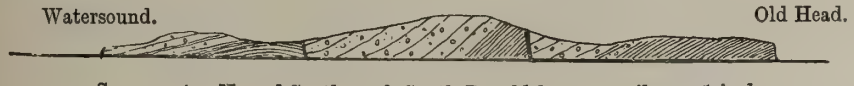
Rocks of an intrusive origin occur also in this district, the principal mass being exposed in the locality last mentioned, about 50 yards west of the ashy sandstone. It forms a mass of about 25 feet in thickness, though its base is not exposed, a dark green rock, which is first seen in the shore, and runs out to sea in a series of picturesque stacks and reefs. Its intrusive character is shown by the absence of any amygdaloidal upper surface, and the evidently unconformable junction with the overlying sandstones. Yet these were, so far as I could make out, not markedly altered, though they are so decomposed that this would not be easy to determine. The rock is about 30 feet beneath the ashy sandstone, and in structure is a much weathered diabase, with crystals of plagioclase felspar, augite, and probably olivine, almost entirely decomposed into green chloritic products, which show traces of ophitic structure. Throughout Deerness, in several places, occur masses of volcanic rock so decomposed and so obscured in their geological relations by the surface accumulations that it is not easy to form an opinion as to their true character. They all occur among the yellow sandstones and the flags associated with them. One is seen to the south of the Free Church, and several outcrops are known in the vicinity of the Public School. I am greatly indebted to Mr Magnus Spence for specimens and observations on these outcrops. From their microscopic structure and the absence of any accompanying tuffs, they are in all probability intrusive sheets. The freshest specimen I obtained was a dark green diabase, with well-marked ophitic structure and pseudomorphs of serpentine after olivine. It came from a deep pit, at one time sunk in a field behind the Public School.†

* Sir A. Geikie, "Old Red Sandstone," *Trans. Roy. Soc. Edin.*, vol. xxviii. p. 406.

† The Black Holm of Copinshay consists of an intrusive sheet of olivine diabase about 30 feet thick, enclosing a large mass of baked flag penetrated by numerous veins. This is probably that referred to by Jameson, *Scottish Islands*, ii. p. 235.

An outcrop of special interest occurs in a field 400 yards west of Smiddybanks. Here, in an old gravel-pit, a face some ten feet high is exposed, now much broken down by weathering. The rock is a coarse red sandy ash, with green spots. In it occur very numerous sandstone and flagstone fragments, some as large as a man's head,—the sandstones baked into quartzites; the flags fused and slaggy on their surfaces, and with their edges rounded. Materials such as these form a considerable proportion of the whole mass. It seems unbedded, or rather the few traces of bedding planes showed a dip discordant with that of the surrounding sandstones. No similar bed crops out along the shore, and the outcrop seems to be limited in area and rudely circular in outline, though, as it occurs in the midst of cultivated land, its exact margins cannot be traced. It is difficult to understand what this is, unless it be regarded as a small volcanic neck, the mixed nature of its fragments being so different from that of the other ash beds, while its position in the centre of the intrusive sheets and lavas and ashes already described renders such a hypothesis, to say the least, highly probable.

There can be no doubt that all these volcanic rocks owe their origin to the same period of volcanic activity. Their situation, almost in the direct line between the Neck of Huna and the lava of Haco's Ness, points to the existence of a north and south fracture or line of weakness, which may be ascribed to the earth movements, which, at the close of the deposition of the Rousay rocks of Orkney, introduced new types of sediment and new forms of life. To the westwards, at any rate, no trace of similar structures has been found. At two subsequent periods volcanic rocks rose to the surface in this district: one series forms the lavas and ash beds of Hoy, described by Sir A. Geikie. These, too, are of basaltic character, but they are separated from those we are at present considering by a great conformity. The others form the trap dykes, which traverse the flagstones mostly in an E.N.E. and W.S.W. direction. But these latter are in no place connected with surface outflows, and differ so widely in structure and composition from the rocks of Deerness and Shapinshay, as undoubtedly to have proceeded from quite distinct sources. They are, in fact, chiefly developed in the West Mainland, and are comparatively few in regions occupied by John o' Groats rocks.



Section 4.—N. and S., through South Ronaldshay. 2 miles = 1 inch.

The only remaining district of the yellow sandstones is the basin of the South Isles. A complete examination of this area I was unable to overtake, but was compelled to confine myself to the islands of South Ronaldshay and Burray, in which they occupy the largest area of any of the South Isles, and very clear sections are to be obtained. Here, also, the underlying yellow series is well developed, and passes down by means of a series of flaggy passage beds into the grey flags, which at the south end of South Ronaldshay contain the Rousay fossils. These passage beds are well seen on the south

shore of Watersound, just east of St Margaret's Hope. At Stews Head they contain a few reddish bands. In South Ronaldshay the yellow series is largely developed, and, with the exception of the district from Widewall to St Margaret's Hope, and thence to Hoxa, they occupy all the areas marked on the map as belonging to John o' Groats beds. A fine section of massive yellow sandstones, with a few flag-beds, is seen extending from Barswick on the west side, north to Herston Head. It is broken by several faults, but there can be no doubt that in thickness it is greater than any other section of the same rocks elsewhere exposed in Orkney. Among these beds no trace of a volcanic zone has yet been discovered, and as yet no John o' Groats fossils have been obtained from any of the South Isles. Their relationships are such, however, as to leave no doubt whatever of their position in the series.

In the district around Melsetter in the island of Hoy, according to Peach and Horne, bands of yellow sandstone occur, overlying conformably the flags which form the south end of the island. These resemble greatly the upper Old Red Sandstones of the west end of Hoy, which unconformably overlie the flags. Now, at the west side of Hoy, opposite Graemsay, the upper sandstones rest on flags which are to be correlated with the Orcadian beds of the opposite shores of Stromness. This is clear proof of the great erosion which must have preceded the deposition of the upper Old Red series in Orkney, as time sufficient for the removal of all the Rousay rocks and all the John o' Groats rocks of Orkney must have elapsed before the upper beds were laid down on the upturned edges of the Stromness flags which form the base of the Old Man of Hoy.

The Red Sandstones of the John o' Groats Beds.

The red sandstones of the John o' Groats beds of Orkney have their greatest development in South Ronaldshay, in the extreme south, and in Eday, at the extreme north of the country, while in the intervening districts their thickness is small. In Eday, they form the entire north end of the island, and thence pass down the centre to Sealskerry Bay. Some of the highest elevations along this line have a height of 350 feet, and the least possible estimate of the thickness of the whole series cannot be less than 600 feet. The yellow sandstones of this island are, however, of only slight thickness, and it is possible that the red beds, in fact, replace the yellow, which further south have a much greater development. Red sandstones form also the south-east corner of the island around the point of Veness. To the geologist these beds are somewhat uninteresting. No fossils have been found in them, and they contain no contemporaneous volcanic rocks. The absence of fossils is perhaps due to the fact that there are no beds of close-grained flag suitable for the preservation of organic remains. The beds themselves consist of coarse red sandstones, often in thick beds, alternating with red shales and marls, with sometimes a greenish or greyish shale. In Eday the sandstones greatly preponderate, and in some places are so coarse as to deserve the title of 'grits.' No traces of any chemical deposit, such as rock salt or gypsum, occur any-

where, and the red matter is uniformly disposed through the rock, except where leached out by percolating water, or where aggregated into irregular layers of iron pan.

In Sanday, along the west shore, the beds have a very similar character, but are more friable, owing to the admixture of dark red clay. In Shapinshay red beds practically do not occur, the only representatives of the John o' Groats beds being the yellow sandstones and flags; but on Holland Head red beds again appear, with every peculiarity to be found in those of Eday. Here, again, the beds are mostly massive sandstones, the red shales being of only secondary importance. The total thickness in this section is about 200 feet. In Deerness, red beds form the western shore of Newark Bay, and stretch westwards nearly to the Castle. Here thick coarse sandstones are mixed with green and red marls. The extreme north point of the parish consists of similar rocks, which are let down by a fault running east and west just south of the Mull Head. They have little of the massive uniformity which characterises the beds of Eday, the alternations in the nature of the sediment being comparatively frequent. Red beds form also the cliff above the Scapa Pier, but in the South Isles area, their best exposure is that from Widewall in South Ronaldshay, by Roeberry, to Hoxa, and thence to St Margaret's Hope along the shore. Here the dip is gentle to north and north-west, and the underlying beds of yellow sandstone pass up very gradually into the deep red marls beneath Roeberry House. The thickness of these marls—which contain thin beds of red sandstone—is considerable, and they resemble closely the beds seen in Calf Sound, in Eday, in every respect, except their greater thickness. Similar beds are to be seen below Smiddybanks in St Margaret's Hope. Overlying these there come in massive coarse red sandstones, which occupy the rest of the area up to Hoxa, where they are faulted against the flags of Hoxa Head. The thickness exposed in this section is about 500 feet, and not greatly less than that of Eday, where the yellow sandstones are so insignificant. The whole thickness of the John o' Groats beds of Orkney may thus be put down at about 1000 feet in its greatest development. Red beds occur also in Burray and Hunda, but these present no features of special interest to merit a separate description.

With these red sandstones the long history of the Orcadian Old Red of Orkney comes to a close. A complete change in the nature of the sediment accompanied what must have been considerable changes in the physical conditions of the area. Yet it is, after all, only a reversion to that type of deposit which elsewhere had been the main one for vast periods of time. In the nature of its rocks and in the limited development of volcanic activity, this area had long been a great contrast to the Old Red of Southern Scotland; only at its close do we find a partial resemblance to make its appearance. The red sandstones are the least important part of the Orkney Old Red. Neither in Caithness nor Orkney do we find them conformably overlaid by any other rock. The new conditions which supervened were marked by the precursors of a new fauna, of which the first example is the Asterolepis, a fish so characteristic of the upper Old Red of the southern shores of the Moray Firth. But before that fauna was to attain its greatest development great changes in the physical geography of Scotland had to take

place, and vast periods of time to elapse. Before the deposit of the upper Old Red of Hoy, much of the Orcadian Old Red had been stripped from the surface of the Orkneys, and very considerable dislocations had modified entirely the old physiography and structure of the country.

III.—*Comparison with the Old Red of other Districts.*

Such being in its main features the structure of the Orkneys, and the subdivisions which can be established by the distribution of the fossils, it remains to be considered how far these conclusions can be applied to other districts in which rocks of like age and similar fossils occur.

The John o' Groats Beds and the Eday Sandstones.

As regards the uppermost beds, the inquiry is a simple one. Rocks containing the same fossils occur in only one locality—the north-eastern angle of Caithness; and here their lithological characters so strikingly resemble those of the Orkney beds that no difficulty whatever can be felt in accepting their zonal identity. The John o' Groats beds of Caithness are, then, to be correlated with the Eday, Deerness, and South Ronaldshay sandstones of Orkney. Sir A. Geikie gives a list of the fossils which have been found in this series in Caithness.* He enumerates, in addition to the three type fossils, *Acanthodes Peachi* (Eg.) and *Glyptolepis leptopterus* (Ag.), neither of which is known to be present in the similar beds of Orkney. It is remarkable how in both counties the fishes characteristic of the lower rocks have been superseded by new types so completely that almost no trace of their persistence is to be obtained. The uppermost zone of the Orcadian Old Red is thus a well characterised one, and may be designated, from the locality in which alone it was known to occur for many years, The John o' Groats Sandstones (zone of *Tristichopterus alatus*, Egert.).

The Thurso and Rousay Beds.

For the representatives elsewhere in Scotland of the lower zones, we must look to two localities, to Cromarty, from which Hugh Miller and Agassiz early in the century furnished a list of fossils, and to Caithness, where, since the time of Hugh Miller and Robert Dick, much work has been done in the palæontology of the Old Red. The earlier work has subsequently been subjected to thorough revision, and a wealth of new material been brought to light by Dr Traquair, to whose papers I am greatly indebted, and on whose published statements I shall rely in comparing the lists of fossils from each locality. In his paper, "Achanarras Revisited" (1894),† he has briefly stated the

* Sir A. Geikie, *Old Red Sandstone*, p. 404.

† Traquair, *Proc. Roy. Phys. Soc. Edin.*, vol. xii., 1894.

results of a comparison of lists of fossils from Caithness, Orkney, and Cromarty, and the result is a division of the known fossils into three groups. One is that we have already considered—the John o' Groats group. The second contains a series of fossils which occur together only in the neighbourhood of Thurso. The list is as follows :—

Homacanthus borealis (Traq.).
Rhadinacanthus longispinus (Ag.).
Mesacanthus Peachi (Egert.).
Cheiracanthus, sp. (perhaps 2 sp.).
Coccosteus decipiens (Ag.).
Coccosteus minor (H. Miller).
Homosteus Milleri (Traq.).
Dipterus valencienesii (Sedgw. and Murch.).
Glyptolepis paucidens (Ag.).
Thursius macrolepidotus (Sedgw. and Murch.).
Thursius pholidotus (Traq.).
Osteolepis microlepidotus (Pander.).
(*Scales, doubtfully resembling those of* Gyroptychius).

It will be observed that this list contains the type fossils of the Rousay series of Orkney, *Coccosteus minor* (H. Miller) and *Thursius pholidotus* (Traq.); and when we compare it with the list of the fossils I have found in those rocks, we find that the following species occur in both :—

Coccosteus minor (H. Miller).
Thursius pholidotus (Traq.).
Dipterus valencienesii (Sedgw. and Murch.).
Glyptolepis paucidens (Ag.).
Cheiracanthus, sp.
Coccosteus decipiens (Ag.).
Homosteus Milleri (Traq.).

With the exception of the first two, these are all contained in the list of fossils which occur throughout the whole thickness of the Orkney flagstones. In Orkney occurs one species not yet found in Caithness, *Asterolepis*, sp. nov., which, considering that it is a fossil of limited range, and confined to a few beds of rock, is an exception of no great importance; and two others present in Caithness, but not known from the vicinity of Thurso, *Osteolepis macrolepidotus* (Ag.) and *Diplopterus Agassizi*. Of these, the latter is one of the rarest of Caithness species, while in Orkney it is quite common, especially in the quarries of Sandwick and Stromness. From the Rousay beds of Orkney I have seen only one satisfactory specimen. It is probable that we have here a case of local distribution, and that the absence of this fossil from the rocks around Thurso is due, not to adverse conditions of preservation, but that rather it was from the first a species characteristic of the more northern area, and hence more likely to persist there, and occur on a higher horizon. On the other hand, we have a number of forms known

to occur near Thurso, but not found as yet in the Rousay beds of Orkney. These are :—

Homacanthus borealis (Traq.).
Rhadinacanthus longispinus, (Ag.).
Mesacanthus Peachi (Egert.).
Thursius macrolepidotus (Sedgw. and Murch.).
Osteolepis microlepidotus (Pander.).

Of these, the first is a rare fossil, and only described for the first time in 1892.* The second cannot be regarded as very abundant, seeing that the British Museum Catalogue (1891) does not enumerate it as a Caithness species. The third has not, so far, been mentioned in the literature of Orcadian geology, though Dr TRAQUAIR, I believe, has obtained a species of Mesacanthus from Orkney this last summer. That these three rarities should be known from the carefully examined rocks around Thurso, and not as yet from the Rousay beds of Orkney, to which attention has only lately been directed, cannot be regarded as a strong argument against the theory that the one series is the northern representative of the other. The two remaining fossils are of more importance, seeing that they are regarded by Dr TRAQUAIR as typical of the Thurso rocks, and confined to them. One of these, *Osteolepis microlepidotus* (Pander.), is very characteristic of them, and abundant in some of the beds ; but I have, at many different times, examined collections of Orcadian fossils, and carefully searched the rocks for this species, without ever obtaining a specimen which Dr TRAQUAIR would admit belonged to it. No doubt it has figured more than once in lists of fossils from Orkney, but the identification is at present more than doubtful. It is possible that we have here a case of local distribution the converse of that of Diplopterus, but at any rate the discrepancy is one which cannot be overlooked, and it is to be hoped that further search in Orkney will bring this fish to light. *Thursius macrolepidotus* (Ag.), it may also be anticipated, will turn up in the Rousay beds, or at any rate its absence is not very remarkable when we remember that only one satisfactory specimen of the other species of the same genus has yet been discovered. Yet that, in that case, in the same quarry, two species which, according to Dr TRAQUAIR, are typical of the Thurso rocks, should have been found together for the first time in Orkney, is a surprising confirmation of the views he enunciated in 1894, that they are type species of a special subdivision of the Orcadian Old Red ; and that their distribution in Orkney, so far as yet known, is in complete accordance with this supposition, has already been proved to be the case. They occur always on practically the same horizon, and in the lowest beds they have never yet been found.

No other locality for these two fossils is at present known, and from the district in which they have been longest and most thoroughly investigated they may be named the Thurso Beds, or the Zone of *Coccosteus minor* (Hugh Miller) and *Thursius pholidotus* (Traq.).

* *Trans. Geol. Soc. Edin.*, 1892.

The Cromarty, Achanarras, and Stromness Beds.

The third group of fossils recognised by Dr TRAQUAIR is that which HUGH MILLER first described from Cromarty, and he himself, on several occasions, from Achanarras (Caithness), and which was long believed to be the only one present in the Orkneys.

The following is a list of the fossils of Cromarty, Achanarras, and the Stromness beds of Orkney .—

Palæo spondylus Gunni,		A.	
Diplacanthus striatus (Ag.),	C.	A.	O.
„ *tenuistriatus* (Traq.),	C.		
Rhadinacanthus longispinus (Traq.),	C.	A.	O.
Mesacanthus pusillus (Traq.),	C.	A.?	O.?
Cheiracanthus Murchisoni (Ag.),	C.	A.	O.
„ *latus* (Egert.),	C.		
„ *grandispinus* (M'Coy),			O.
Pterichthys Milleri (Ag.),	C.	A.	O.
„ *productus* (Ag.),	C.	A.	O.
„ *oblongus* (Ag.),	C.	A.	
Dipterus valencienisii, (Sedgw. and Murch.),	C.	A.	O.
Coccosteus decipiens (Ag.),	C.	A.	O.
Homosteus Milleri (Traq.),	C.	A.	O.
Glyptolepis paucidens (Ag.),		A.	O.
„ *leptopterus* (Ag.),	C.		O.
Gyroptychius microlepidotus (Ag.),	C.	?	O.
Diplopterus Agassizi (Traill),	C.	A.	O.
Osteolepis macrolepidota (Ag.),	C.	A.	O.
Cheirolepis Trailli (Ag.),	C.	A.	O. *

A glance will show the very complete accordance of these lists. All the more frequently occurring fishes are common to all the localities, except possibly *Glyptolepis paucidens* (Ag.), which in the Cromarty district is replaced by the closely allied *Glyptolepis leptopterus* (Ag.). *Gyroptychius microlepidotus* (Ag.) seems to be absent from the Caithness area. The other fishes found in one area only are all rare fossils.

If, now, we examine the list to ascertain which fossils are confined to these areas, we find that—

Palæospondylus Gunni (Traq.)
Diplacanthus, 2 sp.
Pterychthys, 3 sp.
Cheirolepis Trailli (Ag.)

and possibly

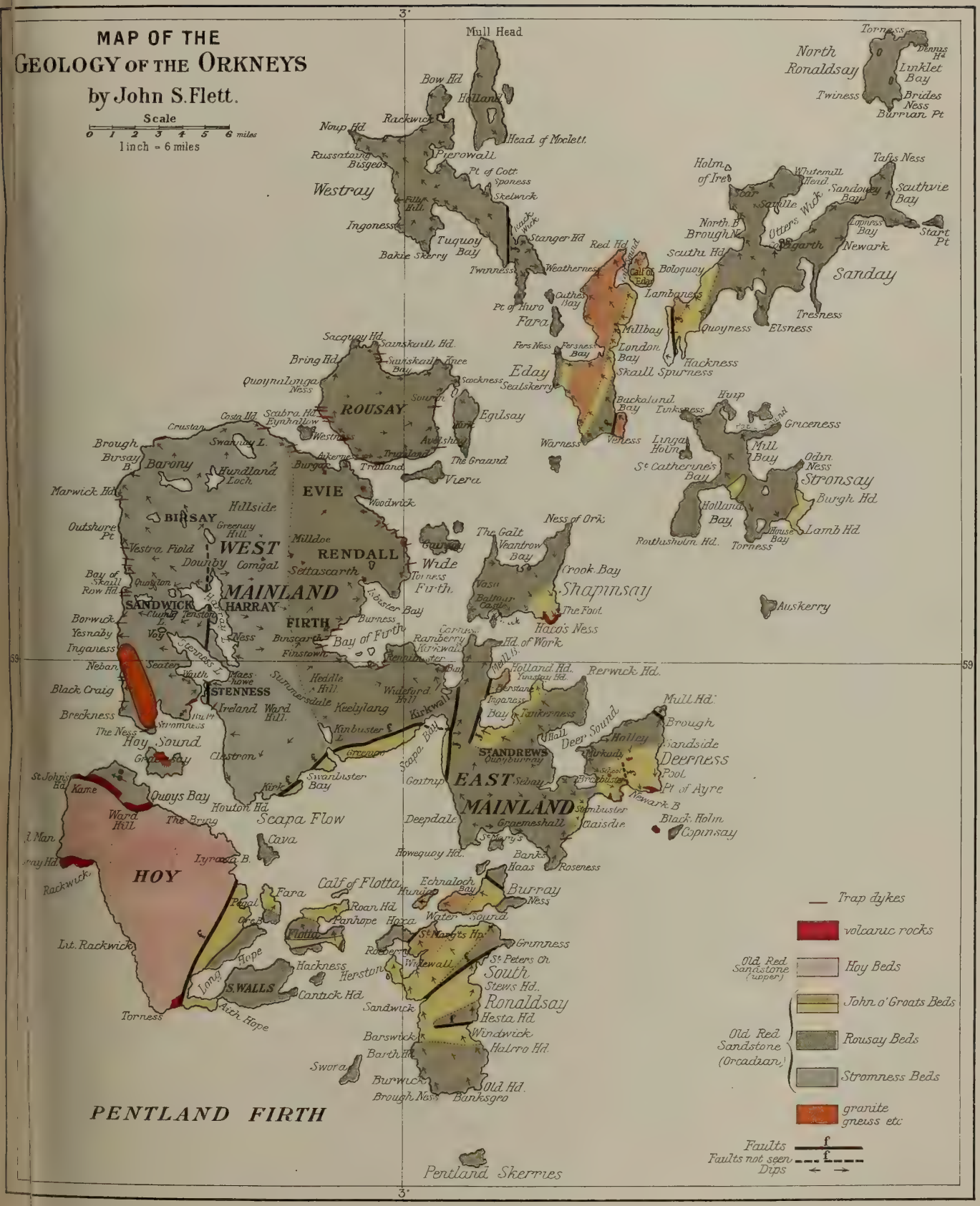
Gyroptychius microlepidotus (Ag.)

are not known to occur elsewhere.

* This list has been compiled from—TRAQUAIR, "Fossil Vertebrates of the Moray Firth"; TRAQUAIR, "Achanarras Revisited"; A. S. WOODWARD, British Museum Catalogue of Fossil Fishes.

To these Dr TRAQUAIR adds two—*Osteolepis macrolepidotus* (Ag.), which certainly occurs in the East Mainland of Orkney, and *Diplopterus Agassizi* (Traill), which, he says, he has not been able to establish with certainty as a member of the Thurso group. If we except the rare *Palæospondylus Gunni* (Traq.), which is known only from Achanarras, we have three genera and six species which, so far as our present knowledge of the distribution of the fossil fishes of the Scottish Old Red Sandstone goes, may serve as type fossils for this group of rocks; and these, it will be remembered, are the genera which I found in Orkney to characterise the Stromness beds; and we may regard it as established that this is a distinct zone of the Orcadian Old Red Sandstone, of which the representatives are the sandstones of Cromarty, Lethen, Gamrie, Clunie, and Tynet, the flagstones of Achanarras in Caithness, and the Stromness beds of the Orkneys.

In conclusion, I wish to acknowledge my indebtedness to those who have assisted me in this work—to Professor JAMES GEIKIE, D.C.L., LL.D., F.R.S., without whose encouragement and advice it would never have been undertaken; to Dr R. H. TRAQUAIR, LL.D., F.R.S., who has determined for me all the more important specimens collected, and has kindly undertaken the description of the new material which turned up in the course of the investigation; to Messrs BENJAMIN PEACH, F.R.S., and JOHN HORNE, F.G.S., of the Geological Survey of Scotland, who have at all times placed at my service their great knowledge of field work, and their intimate acquaintance with the geology of the district. Mr JAMES W. CURSITER, F.S.A. Scot., of Kirkwall, kindly placed at my disposal his fine library of books relating to the county, and his collection of Orkney fossils; Mr THOMAS M'CRIE, of Kirkwall, allowed me also to examine his collection; and Mr MAGNUS SPENCE, of Deerness, gave me most valuable assistance in the field work in that district and elsewhere.



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